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THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

IV. THE PERIPHERAL PHASES OF THE GREAT GABBRO MASS IN NORTHEASTERN MINNESOTA.[1]

C. The Granulitic Gabbros.

THE granulitic gabbros include a large number of different phases characterized by the same general type of structure, but differing from one another in mineralogical composition. Olivinitic varieties occur in small quantity. In these the constituents are the same as those composing the great mass of the normal gabbro, viz., magnetite, olivine, diallage and plagioclase. The rarity of olivine in the granulitic rocks is in marked contrast with its abundance in the gabbroitic variety. In the latter, if one of the components is absent it is usually the diallage. In the granulitic phase, olivine is more frequently absent than present. By its loss diallagic varieties result. But pure diallagic phases of the granulitic rocks are also uncommon, for in the production of the granulitic structure there is a tendency to the formation of biotite and hornblende. Thus biotitic and hornblendic varieties are much more common among the granulitic gabbros than among those with the true gabbro structure. Another quite widely spread constituent in the granulitic rocks is hypersthene. In these, as in the non-feldspathic gabbros, this mineral appears to take the place of olivine.

[1] Continued from this Journal, Vol. II., p. 825.

The Olivinitic Varieties.—The few olivine-bearing granulitic gabbros studied are from places but a very short distance south of the north limit of the gabbro area, and not far north of localities where the normal gabbro occurs in its usual form. They appear to be intermediate in character between the gabbro and the typical granulitic rocks. Their structure is not purely granulitic, for the pyroxene in them is in polysomatic masses rather than in individual rounded grains, although in the same section there may be found in addition to the polysomatic masses a few isolated grains of augite and some compact plates of the same mineral.

The olivine is in fairly large, colorless or light yellow, irregular grains, whose cleavage cracks are marked by grains of magnetite and masses of limonite. Magnetite also occurs as small dust-like particles in their peripheral portions. Green earthy decomposition products surround many of the fresh olivines and extend into their interiors along irregular cracks, and out into the minerals that are contiguous to them. A feature of great significance in connection with the olivine is the fact that many of its grains are surrounded by narrow rims of augite, just as are the olivine grains in the normal gabbro.[1] Since this method of association of the two minerals is so characteristic for the gabbro, which is undoubtedly an igneous rock, there can be no question that the olivine granulitic rocks, though bedded, are closely related to the gabbro, and like this rock are also igneous, and are not metamorphosed sediments. Unfortunately, most of the granulitic rocks contain no olivine, so that the application of this means of identifying them as portions of the great gabbro is very limited.

The diallage appears to be next in age to the olivine. It is in small rounded grains, either isolated or in aggregates so united as to form large masses. The individual grains of the aggregates are often separated from each other by narrow seams of limonite, or by small grains of magnetite, and in their midst is not infrequently a grain of olivine. The mineral is nearly colorless. It possesses the normal prismatic cleavage of augite, and in addi-

[1] See this Journal, Vol. I., p. 702, Fig. 1, and p. 706, Fig. 3.

tion another that reveals itself as a series of very fine lines parallel to the coarser lines of the prismatic cleavage. Its inclusions are little particles of magnetite, small plates of biotite, tiny masses of green and brown earthy matter and a few glass particles.

The existence in these rocks of an aggregation of many small rounded grains of augite in the place of the large plate of this mineral in the true gabbro is strongly suggestive of the polysomatic augites discovered by Lawson[1] in the diabase of certain dikes in the Rainy Lake region, Canada. In the Minnesota rocks the polysomatization of the augite seems to be an intermediate step in the granulitization of the gabbro, not, however, in the sense that all the granulitic rocks have passed through this stage at some time in their history, but in the sense that the polysomatization of the augite is the result of a force similar in character to that which produced granulitization in the granulitic rocks but less efficient in its action.

The plagioclase of these rocks is in allotriomorphic grains of varied sizes and of very irregular shapes in those portions of sections that are poor in augite, and in small and more or less rounded grains where rounded augites and olivines are found. For the most part the feldspar is quite fresh, but here and there little accumulations of kaolin occur in it, and small bunches of green chloritic substance fill the interstices between the neighboring grains. Under low powers all the plagioclase appears to be filled with dust, but this dust under high power is resolved into long needles and small plates of opaque or dark brown substances, and tiny irregular glass inclusions. A few long, narrow, quadrangular cavities and some elliptical ones seem to be filled with liquid, but they are in all cases so minute that it cannot be certain that this is the case. All the inclusions of this character are usually heaped toward the centers of the feldspar grains, with a zone of clear plagioclase around them. In addition to these inclusions there are also imbedded in the feldspar a few rounded grains of augite, and of magnetite, and along the edges of the last named mineral flakes of reddish brown biotite.

[1] Proc. Can. Inst. 1887, Toronto, 1888.

As to the nature of the plagioclase it is difficult to draw accurate conclusions. Measurements of the extinction angles of contiguous twinned lamellæ indicate a labradorite. The most noticeable difference between the plagioclase of these rocks and that of the true gabbro is with respect to their twinning bars. In the latter rock the lamellæ are broad and but few in number, and but one set occurs. In the granulitic rocks the striations are narrow and very numerous. Moreover there are two sets of them inclined to each other at angles of about 90°, and the lamellæ in each set frequently wedge out toward the interiors of the grains in which they occur. Again, small areas near the centers of grains will often have two sets of lamellæ crossing each other, while in other portions of the same grains but a single parallel series is found. Such phenomena as these are usually interpreted as pointing to a secondary origin for much of the twinning in plagioclase. In the present instance a secondary twinning accompanying the granulitization of the rock would indicate that both phenomena owe their existence to common causes. Since the rocks are not sheared, the only causes that can be assigned for them are motion within the rock mass and strains produced by rapid and irregular cooling.

The magnetite, as has already been said, is to be found as small grains included in all the other primary components, and also as irregular masses between them. Whenever it comes in contact with plagioclase, there is formed around it a reaction rim of biotite.

There seems to be no definite order of succession in the formation of the various components. Sometimes the order is magnetite, olivine, pyroxene and plagioclase; at other times the plagioclase is older than the pyroxene while younger than the olivine, and again in a few instances the feldspar appears to be even older than the olivine. With respect to the age of their feldspar the granulitic rocks occupy an intermediate position between the gabbros and the diabases, in the former of which rocks the plagioclase is younger than the pyroxene, while in the latter it is the older component.

Hypersthenic Varieties.—Closely related to the olivinitic-granulitic gabbros are the hypersthene-bearing varieties. In some cases these contain a small quantity of olivine, but in most cases hypersthene has entirely replaced this mineral. A few grains of the usual colorless olivine, for instance, may be detected on one edge of the section of rock No. M. 1347, whereas elsewhere in the slide it is lacking. The main portion of the rock consists of more or less rounded grains of hypersthene and diallage, and irregular masses of magnetite, imbedded in a plexus of irregular but nearly equidimensional grains of plagioclase. Magnetite particles are included within all the rock's constituents, and, since these are very fresh, the magnetite is probably a separation from the magna. The mineral also occurs on the edges of the few olivine grains present, but here it is in long stringers that are evidently secondary.

In the great majority of the hypersthene varieties of the granulitic gabbros no trace of olivine may be detected either in the fresh or in the altered state. Their components are usually hypersthene, diallage, feldspar and magnetite. All are fresh, except in very rare cases when the feldspar shows traces of decomposition. The proportions of the pyroxenes vary widely in different specimens, even to the complete exclusion of one or the other of the two varieties. The purely hypersthenic phases are treated with the other hypersthene bearing rocks in this place, while the purely diallagic kinds are reserved for later discussion.

The hypersthene, the characteristic component of these rocks, is remarkably fresh and transparent. It is pleochroic in the usual light green and pinkish tints, and is often so compact that but few cleavage cracks are to be seen in its grains. An analysis by Dr. E. A. Schneider of a very pure powder of the mineral separated from rock No. 7036, one of the best examples of the type without diallage, gave:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO_2	CaO	MgO	H_2O (105°)	Total[1]
48.44	7.91	.33	20.88	.92	1.44	19.35	.08	97.35

[1] TiO_2 was not determined gravimetrically. A colorimetric test showed about .40 per cent. of this oxide present.

The form of the orthorhombic pyroxene determines in large measure the structure of the rock containing it. In the most purely granulitic varieties this mineral is in the small rounded or subangular grains, which, with the similarly shaped diallage grains and those of plagioclase, together with an occasional particle of magnetite, make up the entire rock. The magnetite is included within both of the pyroxenes and the feldspar, and the pyroxenes are often also enclosed within the plagioclase. The sequence is

FIG. 1.—Granulitic gabbro, with large grains of green hornblende and small rounded ones of augite in a groundmass of plagioclase that appears in ordinary light to be a homogenous mass. The large plates of mineral to the right are hornblende. No. M 1335, x 87.

thus magnetite, pyroxene, and plagioclase, with the hypersthene probably older than the diallage. Figure 1 illustrates the structure of a rock of this kind.

A very peculiar type of structure is that resulting from the occurrence of the hypersthene in cellular grains and plates that are larger than the grains of the other constituents, and less rounded than the hypersthene of the more purely granulitic rocks. These large plates and grains are optically continuous over considerable areas, but are physically not continuous, since they are filled with small and large pores containing plagioclase of the same nature as that occurring between the hypersthene. The plates are very ragged along their edges and have many prolongations with rounded ends. The skeleton-like masses of

the pyroxene in these rocks are thus very similar in their development to the cellular cordierite, andalusite and orthoclase grains described by Salomon[1] in contact rocks. The cellular structure is thought by this writer to be so characteristic of minerals formed by contact action that he has called it the contact structure. In contact rocks it is probably due to the selection of material needed in building up the contact minerals, which would grow around the substances not needed in their construction and thus include them. In the present case the cellular structure of the hypersthene must be an original one, and the direct consequence of the conditions under which the minerals separated from the rock magma. The plagioclase, though included within the hypersthene, is probably the younger of the two minerals, just as the ice, in a frozen sponge saturated with water, is younger than the mass of the sponge which encloses it.

A third form of structure is produced by the aggregation of the hypersthene plates into groups or masses that are imbedded in the granulitic matrix from which hypersthene is wanting. The masses or groups are composed of large irregular grains of the orthorhombic pyroxene, sometimes cellular, sometimes compact, with which are intermingled many grains of diallage and an occasional one of plagioclase. Figure 2 shows a portion of one of these aggregations in the upper part of the picture. In its lower portion is the granulitic mosaic of plagioclase and diallage.

The diallage in all these rocks is in the rounded granulitic forms, except in the rare instances when it is associated with the hypersthene in the aggregates, where it is in large irregular grains. In certain of the non-hypersthenic varieties it is sometimes in cellular plates, but in those containing the orthorhombic pyroxene the diallage, when it occurs, is nearly always granulitic. In the figure last referred to the small, highly refractive, rounded grains are of this mineral. In nearly all cases the diallage is light green in color, is fresh and is without pleochroism. Its inclusions are magnetite grains, small flakes of brown mica and tiny particles of limonite.

[1] Zeits, d. d. geol. Ges., XLII., 1890, pp. 487, 511, *et seq.*

The feldspar of these rocks, like their other constituents, is on the whole very fresh. It is nearly always transparent and colorless, but here and there in some sections it contains opaque or cloudy masses of kaolin and grains of quartz. Its grains are approximately equidimensional. They do not interlock with

FIG. 2.—Granulitic hypersthene-gabbro with aggregates of pyroxenes. A portion of one of these aggregates is shown in the upper portion of the figure. In the lower part is seen the granulitic mosaic of diallage and feldspar No. 8879.

the irregular sutures of granitic feldspar, but they form with each other straight-edged contacts, like the grains of a microgranitic mosaic. In many rocks these grains are of about the same size as the grains of diallage, but in others they are so small that their aggregate between crossed nicols looks very much like a micrographic groundmass in which the larger pyroxene grains are

imbedded. The inclusions discoverable in them are magnetite, small masses of green and brown earthy matter, much of which seems to be in pseudomorphs after magnetite, tiny opaque dust inclusions, small elliptical glass-filled cavities and a few apatite crystals. No liquid inclosures were detected in any of the fresh grains, though a few may be present in those that are slightly decomposed. The twinning of the feldspar is less complicated than was to be expected after studying the olivine-bearing granulitic rocks. Many of the grains are untwinned; more are simple Carlsbad twins; while a few show the more usual parallel bars of the polysynthetic twinning. Most of this feldspar is undoubtedly plagioclase of the same character as is found in the normal gabbro. Its optical properties so far as can be determined are like those of the gabbro feldspar, and the density of a powder separated from rock No. 8879 is 2.715. Some of the untwinned feldspar may be orthoclase, as analyses of some of the hypersthenic granulitic rocks show a large percentage of potassa.

The remaining primary component of these rocks is magnetite. It is found as tiny inclusions in the other constituents and as large grains between them, and sometimes within the pyroxene. The outlines of the grains often show traces of crystalline forms, but almost as frequently they exhibit none.

In addition to the minerals mentioned there is also often present a comparatively large quantity of biotite, but in the hypersthene varieties it seems to be less abundant than it is in those containing none of this pyroxene. When present it is in brownish green flakes so intimately associated with the hypersthene and diallage that it must needs be regarded in some cases as an alteration product of them. Not only are the little flakes abundant on the peripheries of the pyroxene grains, but they are also disseminated all through their substance as very small ill-defined specks whose strong pleochroism and brown color proclaim them to be biotite. In other rocks, in which the pyroxenes are fresh, the biotite is completely wanting, but in No. 7036, one of the freshest of all the granulitic rocks examined, the mica is very plentiful, particularly in the feldspar, as brown wisps and plates.

In this particular case, and in others like it, the biotite seems to be original, at any rate there is no evidence that it is secondary.

Chlorite is another of the unessential components of the granulitic rocks. It is however always in such small quantity that its effect upon the general aspect of these rocks is not marked.

The analyses of two specimens of the hypersthenic rocks follow:

	I.	II.
SiO_2	46.96	49.56
TiO_2	.62	.48
Al_2O_3	14.13	17.81
Cr_2O_3	tr.	
Fe_2O_3	.76	2.76
FeO	14.95	9.48
NiO	.06	
MnO	.93	.06
CaO	2.32	9.70
MgO	15.97	5.93
K_2O	1.68	
Na_2O	.35	2.87
H_2O at 105°	.07	} .50
H_2O above 105°	1.26	}
P_2O_5	.03	.67
Total	100.09	99.82
Sp. Gr.	3.193	2.967

I. Granulitic hypersthene-gabbro. Very rich in hypersthene and biotite and poor in feldspar. Much of the latter is unstriated. Analyzed by Dr. H. N. Stokes. No. 7036.

II. Granulitic diallage-hypersthene-gabbro. Diallage much more abundant than hypersthene. No mica. Most of the feldspar striated. Analyzed by W. H. Melville. No. 8879.

Diallagic Varieties.—The great majority of the granulitic gabbros contain neither olivine nor hypersthene. These rocks consist essentially of diallage and plagioclase, or of these minerals with biotite and hornblende. The varieties without the last two named minerals are not as common as those containing them. Indeed, only three sections of diallage rocks free from biotite

have been seen, and in these the structure is slightly different from that of the typical granulitic rocks. The plagioclase in them is more or less lath-shaped and the augite grains in many cases possess idiomorphic outlines. In section M. 458 H. for instance, the pyroxene occurs in two forms, viz., in small fresh, greenish, partly idiomorphic grains that produce with the small more or less lath-shaped grains of plagioclase a granulitic aggregate, and in large altered crystals, filled with magnetite. The

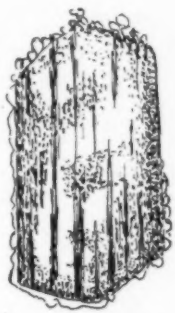

FIG. 3.—Idiomorphic pyroxene in granulitic gabbro, surrounded by granulitized augite. M. 458 H. x. 30.

outlines of many of these larger grains are clearly the result of the crystallizing force, but, nevertheless, they are not sharply defined, since their peripheries are slightly granulated (Fig. 3). Within the granulated portion, however, the original contours of the crystals remain, so that the granulated peripheries are not properly granulated portions of the original crystals, as in the cases described by Professor Judd,[1] but are rather additions made by small grains adhering to the exteriors of the large crystals. In the Scottish occurrence the interiors of the grains did not assume a definite crystallographic form before the granulated pyroxene was produced. Here the homogeneous nucleus passes gradually into the granulitic portion in consequence of "Crystallization having gone on to a certain extent, while the [rock] mass

[1] l. c., Fig. 4, Pl. VII., p. 94.

was in a state of perfect internal equilibrium," and then having been concluded, after some internal movement or strain had been set up within it. In the Minnesota rock the crystal of pyroxene was completely formed before the granulated portion was added to it. The crystallization of the diallage took place in two distinct stages, first, while the rock's material was in a state of internal equilibrium, during which period the perfected crystal was formed; and, second, at some more recent period, when a change in the conditions under which the rock-mass existed afforded a favorable opportunity for the formation of a second generation of augite, which took the form of granulitic grains. The crystal above pictured is the most perfect one in the section. Others no longer possess such a distinct outline. An interior nucleus heavily charged with magnetite or black earthy decomposition products is surrounded by a clearer zone of light green pyroxene with few inclusions of any kind, and this in turn passes into the granulitic material; or a fairly clear interior may be surrounded by a zone of decomposition substance, marking the outline of the original crystal, and this be enveloped by a clear zone with its attendant granulitic periphery. In all cases, however, it is plain that the pyroxene separated from the rock-mass in two entirely distinct stages.

The second generation of diallage forming, with the plagioclase, the granulitic groundmass in which the larger grains lie, is in very light green, almost colorless grains measuring from .03 to .15 mm. in diameter. They are usually longer than they are broad, thus giving rise to short prismatic forms, on which occasionally crystal faces may be detected. They include small particles of magnetite and are themselves often enclosed in plagioclase.

The last named mineral likewise appears to be in two generations. At any rate it occurs in good-sized lath-shaped grains, and in smaller ones with badly-defined rounded outlines. Magnetite is included in both varieties in large quantity.

Of the few remaining components magnetite and biotite are the most important. The former is in large irregular grains

between the diallage and plagioclase, and in small grains or particles included within them. Much of it may be primary, but most of it is undoubtedly secondary. The biotite is found principally between magnetite and plagioclase as a reaction rim around the former mineral, although in some instances it appears to replace pyroxene.

In many specimens of these rocks the pyroxene is quite fresh. In other sections the diallage has undergone a change by which hornblende has resulted. This is in the brownish-green indefinitely outlined flakes and plates characteristic of secondary hornblende. It occurs principally in the outer portions of the larger crystals, but sometimes it extends inward until it replaces their entire substance. The granulitized augite of the groundmass in which the porphyritic crystals are imbedded is also occasionally changed into hornblende, but only when in the near vicinity of the larger grains. Most of the granulitic augite is unaltered.

Biotitic and Hornblendic Varieties.—As the biotite and hornblende in the granulitic rock increase in amount the pyroxene decreases until the first two minerals begin to affect materially the character of the rock and to give it a distinctive aspect in the thin section. Sometimes the biotite occurs unaccompanied by hornblende, though this is rarely the case. It usually occurs together with the amphibole, with the latter in no inconsiderable quantity.

The biotite is in two forms, either as small plates with the general outlines of small granulitic augite grains, or in larger very irregular flakes, many of which are so closely associated with magnetite that they must be considered as having originated through its alteration. The smaller plates of the mica and much of the material of the larger ones are very probably alteration products of pyroxene. The former have the same shapes as the granulitic grains of this mineral, while the latter often seem to grade insensibly into comparatively fresh augite substance. Some of the plates surround cores of fresh diallage from which they are separated by a sharp line and some occur as well-defined plates scattered indiscriminately among the components of a perfectly fresh rock. These are probably original.

Nearly all of the hornblende that appears in these sections is quite evidently an alteration product of the augite. It is in large plates of a dirty greenish or a greenish brown color, according to the position above the lower nicol. The outlines of these plates are always ragged, and they bristle with projections that extend beyond the main mass of the plate far between the neighboring plagioclase grains. As the augite changes into hornblende, the new substance produced orientates itself uniformly until the products of a dozen or so grains become merged into a single plate, which naturally includes a large number of feldspar and magnetite grains, and of biotite flakes, provided any of these happen to have been formed before the hornblende. The structure of the plates is exactly analogous in its origin to that of Salomon's contact minerals, as it is here produced by selection of augite grains and the enclosure of those minerals that were not suitable for alteration into amphibole. When the small grains of augite are too widely scattered to affect the hornblende produced by their alteration, this substance occurs in isolated particles with independent orientations. That these little isolated grains are secondary in their origin is learned from the fact that many of the granulitic augites are partially changed into the same mineral, some only on their edges, and others throughout nearly their entire masses. In many other sections the hornblende is evidently original, in which case it has the same properties as the least decomposed of the secondary amphibole. In rock No. 7061 for instance the hornblende is more irregular in its outline than the diallage, though it usually possesses right-lined contours rather than sinuous ones. In color it is brownish green with absorption as follows: $\mathfrak{c}=\mathfrak{b}=$brownish-green$>\mathfrak{a}=$ pale yellow. Its grains occur between those of plagioclase, and they include magnetite, diallage and round or elliptical colorless inclosures like those observed within the pyroxene. Cross sections of crystals with the characteristic contours and cleavage of hornblende are not very uncommon. Although this hornblende is not unlike the secondary amphibole in others of the granulitic rocks it is not possible to regard it as due to the alter-

ation of augite or of any other mineral now occurring in the rock.

In those phases of the granulitic rocks that contain large quantities of biotite and hornblende, the former mineral is often in large plates with irregular outlines and the cellular structure that has been referred to so frequently as characteristic of the constituents of these rocks. On its basal section the mica is reddish brown. Parallel to the cleavage it is almost opaque, while perpendicular thereto it is yellow. It includes grains of augite and is often included in plagioclase. Most of the diallage in these rocks has disappeared and has been replaced by yellowish brown hornblende in grains of the same shape and size as the few augites remaining. In some sections that are otherwise quite fresh, individual augite grains are changed into hornblende often to half their extent. At some distance from their contact on either side of it the augite and the hornblende are well characterized. Near the contact their special peculiarities blend to form an intermediate substance that is neither a well defined pyroxene nor a typical amphibole. The structure of most of these varieties of the granulitic rocks is typically granulitic. There are a few cases, however, in which a departure from this structure is noticed. In rock No. 8900, for instance, the plagioclase grains are not all of nearly the same size. Large grains, with very ragged contours and small grains of the granulitic character are both common in it. The former measure between .5 and 1. mm. in length and the latter rarely more than .1 mm. No distinction as to age between the two feldspar can be made out. Sometimes the large grains seem to be younger than the small ones, and often they appear to be older. Both are more or less kaolinized and both include augite, hornblende, small colorless crystals and glassy particles. The other exceptions to the characteristic granulitic type are no more striking than is this.

Non-feldspathic Varieties.—The only granulitic rock free from plagioclase is No. 1334, which has already been referred to in another place (Vol. II., p. 824). This rock is more or less

schistose. It is composed almost exclusively of colorless pyroxene and colored hornblende. Most of the latter mineral is of the character already so frequently described, but there is in addition a little bright green amphibole fringing areas of the brownish green variety. The fresh augite and the hornblende are both principally in small rounded grains closely packed together, producing a mosaic, polarizing brilliantly between crossed nicols. Locally in the section the augite granules unite to form a fairly compact plate of this substance. In one place a large nucleus of compact augite is surrounded by a broad irregular zone of small grains of exactly the same substance. The interior is crossed by many irregular lines that divide it into a large number of small grains, but all of these are uniformly orientated, and between crossed nicols they polarize together. In the outer zone the individual grains are slightly removed from one another, and consequently each polarizes independently of all others. In a recent description[1] of this rock it was intimated that the granulitic outer zone had been caused by the fracturing of the large augite grain and the movement of the broken portions from their original positions. A more careful inspection of the section teaches that this may not be the method of formation of the peripheral granulitic zone. Movement in the rock-mass during consolidation of the granules and posterior in point of time to the formation of the nucleus has certainly been instrumental in causing the complex orientation of the granules in the outer zone, but that these latter represent fragments of an original large grain is not now believed.

D. Conclusion.

The above-described phases of the gabbro have been discussed in more detail than their petrographical interest would seem to justify, mainly because their eruptive origin appears to have been called into question.

The microscope has shown so conclusively that the rudely bedded basic and fine-grained dark rocks, interlaminated with

[1] Geol. and Nat. Hist. Survey of Minn. 19th Ann. Report, p. 196.

the quartzose bands along the northern border of the normal gabbro, are but phases of the latter rock, that a thorough field study of the relations existing between these rocks and the gabbro does not seem necessary to their correct understanding, however much it may be desirable. All the field work which has been done in the neighborhood of Akeley Lake, however, so

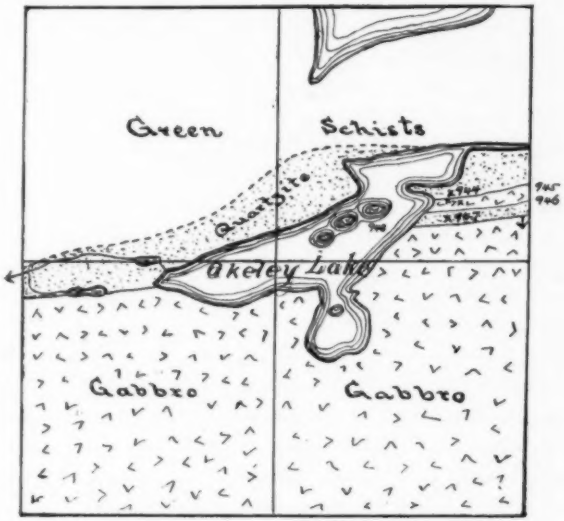

FIG. 4.— Preliminary geological map of the vicinity of Akeley Lake, Sec. 29, T. 65 N., R. 4 W., Minnesota. From manuscript map furnished by Dr. U. S. Grant, of the Minnesota Survey. Scale, 3 inches to mile.

far as it goes, confirms the conclusions of the microscope. A map of this region has kindly been furnished the writer by the Minnesota Survey through the courtesy of Dr. U. S. Grant. It is reproduced in Fig. 4.

The rock south of the lake is the normal olivine gabbro. On its northern side this is in contact with the crystallized quartz-olivine-pyroxene rocks, to which reference has already been made (Vol. II., p. 816). On the map they are marked "quartzite." Between the main masses of the "quartzite" and the gabbro a

repetition of bands of these two rocks intervenes, so that the gabbro area appears to pass gradually into the "quartzite" area. Two large bands are shown on the map, to the east of the lake, but these bands are not composed exclusively of the quartzose rock or of gabbro. The gabbro band contains on its borders small bands of "quartzite," while the large "quartzite" band is interlaminated with several narrow bands of gabbro. When thick these interbanded gabbros are similar in every respect to the normal gabbro further south, except that they may contain more hypersthene; when thin they are basic or granulitic phases of this rock.

The quartzose rocks contain a large quantity of gabbro material, such as olivine, diallage, hypersthene, etc., which can only have come from the gabbro in contact with them. The origin of these rocks has not yet been worked out.

Of the specimens indicated on the map No. 944, from the southern edge of the northern "quartzite" area is a quartzose rock saturated with gabbro material, and interbanded with narrow seams of granulitic gabbro. No. 495, near the contact between this rock and the large gabbro band, is a granulitic gabbro, with a diabasic structure in places. No. 946, from the center of this band, and No. 948, from the easternmost island in the lake, are normal gabbros containing some hypersthene. No. 947 is like No. 944.

Before concluding this discussion it seems necessary to refer to some misconceptions that have arisen with respect to the author's position regarding the Pewabic quartzite.[1] In the nineteenth report of the Minnesota Survey he describes a few specimens sent him by Professor Winchell from the vicinity of Akeley Lake. Some of these were labeled "Muscovados" and others "Pewabic quartzite," and were referred to under these names in the annual reports of the Survey. The "muscovados" were found, upon microscopical examination, to be mainly phases of gabbro, and the "quartzites" to include two distinct rocks, viz., granulitic and

[1] W. S. BAYLEY: Nineteenth Ann. Rep. Geol. and Nat. Hist. Survey of Minn. Pp. 193–210.

basic gabbros and quartzose rocks like those referred to above as "quartzites" in the account of the geology of Akeley Lake. Hence it was concluded that the "Pewabic quartzite," *as described from the Akeley Lake region*, could not be used as a definite horizon for correlation purposes, since so much of it is gabbro. This opinion is still held; but the writer may have been mistaken in his views regarding the origin of the quartzose rocks interbanded with the gabbros. None of those seen, are, in their present condition, fragmental sediments, nor can any trace of clastic grains be detected in them. Nevertheless, it is possible that they may be re-crystallized quartz rocks.

The basic layers interbanded with the quartzose ones are, however, not "tufaceous, eruptive fragmental elements,"[1] and cannot be a part of any distinct horizon to which the name Pewabic quartzite may be applied. These bands are igneous and are not chemical sediments, nor are they metamorphosed quartzites.

The main purpose of the paper referred to, however, was not the discussion of the Pewabic quartzite. It was the determination of the age of the gabbro, and upon this question it was supposed to have added some evidence in opposition to the view that the gabbro is of Animikie age, although Professor Winchell[2] was inclined to regard its evidence as favorable to that view.

The descriptions of the granulitic and basic gabbros so closely associated with the normal gabbro show that these rocks are not sediments, but are parts of the gabbro, and hence cannot be used for determining the age of the latter rock.

If the quartzose rocks with which they are interbanded are metamorphosed Animikie strata then the proof of the post-

[1] PROFESSOR N. H. WINCHELL: Footnote, 19th Ann. Rep. Geol. Survey Minn., p. 210.

[2] "Of course the intent of Professor Bayley's paper is to establish the idea of Professor Irving that the gabbro flood is later than the Animikie rather than near the bottom of it, where the Minnesota geologists have placed it, but its purport confirms the Minnesota geologists in their conclusions."—*Professor Winchell, in footnote referred to.*

Animikie age of the gabbro is conclusive. As further evidence on this question Dr. Grant[1] reports that in the neighborhood of Gunflint Lake "the gabbro was found to include fragments of the Animikie slates, and it also was found directly overlying and in contact with beds of the upper member of the Animikie. This gives additional proof of the post-Animikie age of the gabbro."

W. S. BAYLEY.

[1] 22d Ann. Rep., p. 77.

A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.

PART II. PETROGRAPHICAL DESCRIPTION.[1]

Classification.—While limestones and other non-eruptive rocks occur in the region at present under description, yet they offer no special features of interest and will not be touched upon further. What will chiefly engage our attention are the eruptive rocks proper which make up by far the greater part of Ægina and Methana, with the eruptives from the neighboring and closely related localities of Poros and Kolautziki. Some space will also be devoted to the segregations found in the lavas and to the tuffs.

The eruptive rocks may all be referred to the two well defined groups of andesites and dacites, but a few words must be devoted to the classification here adopted before we begin their description.

The distinction between the two main groups, as defined by Zirkel,[2] does not depend solely on the presence or absence of quartz but on the superabundant amount of SiO_2 whether it has crystallized out or not, exactly as is the case with the trachytes and rhyolites. In the case of the rocks before us there is, as usual, some difficulty in drawing a fast line between the two; but, as a basis for the distinction I have used the percentage of silica, those rocks having over 62 per cent. being classed as dacites, those with less as andesites. As it was impracticable to have analyses made of all the specimens I have had to judge in some cases by the presence or absence of quartz grains, or by analogy and association, so that, though we may be left in doubt in a few cases as to where to place a given specimen, yet on the whole the discrimination is made with comparative ease, and the

[1] Continued from Vol. II., p. 813.

[2] ZIRKEL, Lehrb. v. Petrog. 2d ed., 1894, p. 569.

errors will not affect the general conclusion that may be drawn from the observations.

The sub-classification of these two main groups allows of more latitude, but is readily done by means of the ferro-magnesian silicates, the writer preferring this to a classification based on structure such as Rosenbusch adopts for the dacites.[1] It must be borne in mind that between some of the groups gradations occur, though on the whole there is less difficulty from this source in the present district than in many others. In the final classification then I have followed in the main that of Küch[2] for the closely similar Colombian eruptives, though my scheme differs from his in distinguishing between the augite and the hypersthene-andesites.

I divide then the dacites into: *Hornblende-Dacite; Hornblende-Hypersthene-Dacite*, and *Biotite-Dacite*.

The andesites are divided into: *Hornblende-Andesite; Biotite-Hornblende-Andesite; Hornblende-Augite-Andesite; Hypersthene-Andesite*, and *Hornblende-Hypersthene-Andesite*.

It may seem unwise to give a mixed, and from a certain point of view a subordinate, group like the last as much prominence as a chief group such as the hornblende-andesite; but, leaving other considerations aside, it must be remembered that the present classification is merely for purposes of description in this paper, and not intended for general use. It has the further advantage, in the present case, of making the petrographical groups correspond, to a large extent, with their geological and geographical divisions.

Hornblende-Andesite.—Rocks belonging to this group compose the whole of the Stavro district, *i. e.*, Mts. Stavro, Palæochora, and Spasmeno Vouno, and are found as well along the north slope of Mt. Chondos, or Mt. Dendros, and at a small hill south of Kakoperato. While these various occurrences greatly resemble each other fundamentally yet there are certain small differ-

[1] ROSENBUSCH, Mikr. Phys. II., 1887, p. 638.

[2] REISS and STÜBEL, Reisen in Süd Amerika. Geol. Stud. i. d. Rep. Colombia, I., Petrographie. 1. Die Vulkanische Gesteine von R. Küch, Berlin, 1892, pp. 18 and 19.

ences. The rocks of the Stavro district, on account of their quantity and importance, will be taken as the type and described in detail.

Megascopically they show a largely preponderating light gray groundmass with a slightly pinkish cast which is dull in luster but very compact and fine grained, there being no gas pores or vesicles. The specific gravity of the Stavro rock is 2.508, that of Spasmeno Vouno being 2.327. The latter differs slightly from the former in being of a purer gray color and with groundmass rougher in feel and not as fine grained.

Quite abundant phenocrysts are scattered through this groundmass but with no trace of arrangement in lines of flow. The majority of these are greenish black hornblende prisms from 0.5–2.0 mm. long. There are also seen a few stout, black, hexagonal prisms of biotite measuring 3–5 mm. each way, the interior of these often containing minute white grains which seem to be plagioclase. Many plagioclase phenocrysts are also present, of a dull white color and showing cleavage faces and occasionally twinning striations. In the specimens from Spasmeno Vouno are seen three or four pink quartz grains about 2 mm. in diameter, not surrounded by an augite fringe.

No segregations ("endogenous enclosures") were seen in the whole district. In one or two specimens there are yellowish green streaks colored by epidote and due to subaërial decomposition, and some of the plagioclase phenocrysts are colored yellow from the same cause. The rocks of Spasmeno Vouno are all more decomposed than those of Mt. Stavro, the best specimens from which are quite fresh.

The hornblende-andesites from the other localities differ from those just described chiefly in the greater abundance and larger size of the phenocrysts, among which also plagioclase is the most important; the groundmass resembles, as a rule, that of Spasmeno Vouno, being not very compact and rough in feel. One or two of the specimens from Mt. Chondos are decomposed and of a pinkish brown color.

Under the microscope these andesites show a groundmass

made up, to a large extent, of colorless or very pale brown glass base, this being much more abundant in the Spasmeno rock than in that from Stavro. In this base are strewn quite abundant plagioclase lathes[1] and small colorless microlites, some of which seem to be augite, many small magnetite grains, and (especially in the Stavro rocks) much brown "dust" in streaks and patches. A flow structure is developed among these smaller constituents, which is especially well marked in the Spasmeno rocks, where also the "dust" is almost entirely absent. There are also to be reckoned among the groundmass constituents a number of small plagioclase crystals and green hornblende prisms.

The discrimination between the phenocrystic and the groundmass plagioclase is quite easy, as the latter is almost always in the shape of small clear lathes, while the former is in much stouter crystals and generally with inclusions. The plagioclase phenocrysts are of fair size, and, under the microscope, seem quite fresh and unaltered. The stout crystals show the usual planes and very few fracture surfaces are to be seen. Twinning lamellæ, in nearly every case according to the albite law, are common and the extinction angles of 29°–30° 30′ on *c* (001) indicate that we have here a bytownite of about the composition $Ab_1 An_4$, though in all probability other members of the series are present. Such a basic plagioclase is unusual for hornblende-andesite whose feldspar is generally labradorite or andesine, and I very much regret that the lack of proper facilities in Venice, where this paper was written, prevented the examination of the feldspar by other methods. The small lathes also belong to the bytownites, but at the end of the series richer in albite. Zonal structure is quite frequent.

Inclusions are very common in the larger crystals and in the great majority of cases are of generally clear brownish glass, occasionally dusty, and frequently holding a bubble. In many cases these glass inclusions are so numerous that they form a

[1] The term "lathes" is used for the larger, but still small, long groundmass crystals (especially of feldspar), while microlites are the smallest in size and in many cases of an indeterminable nature.

sort of "network" of the plagioclase, the meshes being of glass. This "net" usually forms a core of the same shape as the crystal with a narrow, clear, inclusion-free zone of plagioclase surrounding it. In other cases there is a central core of clear feldspar, then a "network" zone, and finally an outer clear border. Belowsky observed similar inclusions in the feldspars of andesite from West Ecuador,[1] and they are not infrequent elsewhere. Besides these glass inclusions some small clear hornblende crystals, magnetite grains and apatite needles are also to be seen as inclusions in the feldspar.

One of these apatite inclusions which is of special interest consists of a slender prism with low pyramidal terminations, .025 mm. long, from one side of which projects a smaller prism at an apparent angle of 47°. This must be regarded as a twin and identical with the apatite twin from North Carolina[2] described by me, with twinning plane *s* $(11\bar{2}1)$ and the angle between the *c* axes of 68° 28′. The lesser angle in the present case is accounted for by the fact that the twin does not lie with the plane of its two axes parallel to that of the section, as is seen on the use of higher powers. This occurrence is interesting since it serves to confirm the view that the first described case was a true twin and that the plane *s* $(11\bar{2}1)$ is a twinning plane of the species.

The hornblende of these andesites, which occurs in well shaped, though often broken, crystals (the uncommon plane *a* (100) being often largely developed) is noteworthy on account of its color. This is a light, rather bright, olive-green, the pleochroism being very strong; **c** dark olive-green, **b** olive-green, **a** pale yellowish green. This color is characteristic of the hornblende of all this group, with the exception of one specimen from Mt. Chondos which seems to have undergone decomposition to some extent. Here the hornblende is of a dark or brownish green color, and the very strong pleochroism is: **c** dark orange-

[1] REISS and STÜBEL, Reisen in Süd Amerika. Das Hochgebirge d. Rep. Ecuador I. Petrog. Untersuch. I. West Cordillers, Tulcan bis Escaleras Berge von M. Belowsky, Berlin, 1892, p. 28.

[2] Am. Jour. Sci., XXIII., 1887, p. 504. *Cf.* DANA: Mineralogy, 1892, p. 767.

red, $\mathfrak{b}$ dark red-brown, $\mathfrak{a}$ light yellow-green. In this case it must be noted that some of the hornblendes are of that dark red color which, as Belowsky[1] has shown, is produced by heating the green variety. The occurrence of green hornblende in the andesites is rather unusual, the color being generally brown. As is well known the green color is characteristic of the propylites, but the present rocks show none of the well marked features of this group, and are in every other way typical hornblende-andesites. The extinction angle is 11°.

The hornblende is in every case, except that mentioned above, perfectly fresh and unaltered, the dusty edges of some of the crystals, which look at first sight like incipient alteration, being seen on closer examination to be due to overlapping layers of the dust-laden groundmass. Zonal structure is occasionally seen, some of the crystals having the commonly observed darker green core. Inclusions are not common and small, though of considerable variety; small crystals of biotite, augite, plagioclase and magnetite, with an occasional zircon or spot of brown glass, having been noted. The distinction between the phenocrystic and the groundmass hornblende is hard to draw as they grade into each other with no difference of habit.

Augite is not abundant in these rocks, though occurring here and there in small crystals, clear and almost colorless. Intergrowths of this with the hornblende are not unusual, in one case the augite occupying the center and the hornblende forming the outer part of the mixed crystal; while in other cases one end is augite and the other end hornblende. A very few sections of biotite were seen in the slides; they are greenish gray, quite fresh, and carry inclusions of plagioclase and magnetite.

Magnetite is quite abundant in the form of fine grains in the groundmass as well as larger crystals up to 2 mm. in diameter. These last not infrequently show inclusions of plagioclase, apatite and zircon, and even, as in one case, have grown around the present groundmass. Many of these larger crystals show a coppery brown luster by reflected light, and, on the edges and

[1] BELOWSKY. Op. cit., p. 37.

in the thinnest spots, a granular structure, the grains being semi-transparent, of a chestnut-brown color and isotropic between crossed nicols.

The fresh appearance of the rock and the crystals, and the absence of a surrounding border of brown limonite, seem to preclude the idea that their appearance is due to weathering, though they somewhat resemble the limonite pseudomorphs after magnetite observed by von Lasaulx[1] in some altered basalts from the Auvergne. In color and physical characters the grains bear a great resemblance to the crystallites in the Bobenhausen tachylyte[2] which Zirkel[3] holds to be an extremely ferruginous glass. It may be, then, that these large magnetite crystals are in reality pseudomorphs of such a glass after the original magnetite, due to the combination of the latter with the magma.

A curious fact is that the majority of these larger magnetite crystals are accompanied by perlitic cracks in the groundmass, which surround the magnetite at a short distance from it either completely or partially, there being sometimes only one and sometimes several such cracks about each grain. These cracks are not met with elsewhere in the groundmass, nor do they surround any of the other minerals, and their formation may be connected with the brown coloration and granular structure just described. It must be noted that the groundmass between the cracks and the magnetite grains, quite up to the latter, is entirely normal and identical in color, structure, etc., with that elsewhere.

In addition to their green hornblende these andesites are specially marked by the presence of tridymite, which is very common, especially in the rocks of the Stavro district. This occurs in small irregularly-shaped masses or round rosette-like clusters showing the usual shingle structure, or in radially arranged spherical aggregates, about 0.1 mm. in diameter. As they often occupy the sides of small cavities they seem in part to be of secondary origin, but this is not at all certain.

[1] Neu. Jahrb., 1870, p. 695.

[2] *Cf.* VOGELSANG, Die Krystalliten, Bonn, 1875, p. iii., and Pl. XIV., Fig. 1.

[3] ZIRKEL: Basalt Gesteine, Bonn, 1870, p. 182, ff.

The above description will apply on the whole to the hornblende-andesites from the other localities, though in these last the phenocrysts are much more abundant. In two of the specimens, from Mt. Dendros and from the ridge southwest of the monastery, the groundmass is markedly spherulitic. The spherulites belong to Vogelsang's globospherites, being rounded aggregations of brownish dusty globulites and some trichites, arranged so as to give to the spherulite a fine radially fibrous structure. Surrounding this fibrous granular center, which has no action on polarized light, is a narrow border of clear, colorless isotropic glass substance. The groundmass of these spherulitic andesites is very vitreous, and with many perlitic cracks.

Biotite-Hornblende-Andesite.— The only representative of this group is the rock which forms the small promontory on which stands the town of Poros. Megascopically the specimens resemble much more the lighter hornblende-augite-andesites than the rocks just described, having a fine-grained gray groundmass containing very many plagioclase crystals and small hornblende needles. In this — generally arranged in lines of flow — are very numerous phenocrysts, chiefly of white plagioclase with stout black hornblende prisms and many biotite tables; grains of quartz are very rare. Much of the rock is partially decomposed and then assumes a reddish brown color, the plagioclase being tinged with yellow, and the biotite tables acquiring a brilliant submetallic bronze-luster resembling that of phlogopite.

Under the microscope they show a groundmass of largely preponderating colorless glass base, containing many small microlites chiefly of plagioclase, with plagioclase lathes, small, fresh, greenish brown hornblende crystals and but little magnetite Flow structure is beautifully developed in the groundmass, and segregations are quite frequent.

The phenocrysts of hornblende are of the same greenish brown color and perfectly unaltered; in the decomposed specimens however being decidedly brown, with no traces of a green tone, but still remaining perfectly clear. Biotite crystals are quite common, of an olive-green color when unaltered, but in the

less well preserved specimens of a reddish brown or brilliant orange. Some of them are bent and show frayed ends. The plagioclase calls for no special remarks; twinning lamellæ are common and the extinction angles of nearly 30° show that it is a bytownite. A few clear colorless augite crystals are also present.

The rock from this locality has been described by R. Lepsius[1] who states that the feldspar is orthoclase, does not mention the very abundant hornblende, states that the rock contains 60.21 per cent. of SiO_2, and calls it a trachyte and the same rock as that which occurs at Kalamaki and Kolautziki, which last, as we shall see later is not the fact. He seems to have examined but one hand specimen, and that more or less weathered. My study of the rock *in situ* and of the three specimens brought back with me does not bear out his view that it is a biotite-trachyte. The feldspar is all, with scarcely an exception, undoubtedly plagioclase, hornblende is abundantly present, and the slightest comparison of the specimens in my possession show that the Poros and the Kolautziki rocks are quite different. It is possible that Philippson may have collected a specimen quite different from mine, but if so it must be of a subordinate facies and not from the main mass of the Poros dome. In the few hours which we spent at Poros I went over most of the small hill and found only the rocks such as have been described above. The main body of the rock of Poros must then be with certainty regarded as a biotite-hornblende-andesite and not as a trachyte.

Hornblende-Augite-Andesite.—The chief rocks of the central part of the island of Ægina belong to this group as it makes up the main part of Mts. Chondos, Pagoni, Dendros and Gaiapha, with probably many of their outlying spurs.

Megascopically they differ considerably from the rocks to the north and south of them, showing a highly porphyritic structure with very numerous phenocrysts, the latter being in some cases so abundant as to give the rock almost a granitic appearance. The phenocrysts are almost entirely plagioclase, with few hornblende prisms and still fewer biotite tables, no quartz grains

[1] PHILIPPSON. Op. cit. p 604, *cf.* ZIRKEL, Petr. p. 258.

being seen in any of the specimens. The groundmass is almost without exception dark gray, in some of the Mt. Chondos specimens almost black, quite compact and occasionally with a subgreasy luster. The rock near the tuff at the west end of Mt. Chondos shows a banded structure of alternate dark and light gray streaks,which run almost vertically ; they are best brought out on slightly weathered surfaces.

The only exception to the above general description is the hornblende-augite-andesite specimen from a small hill or ridge southeast of Kakoperato, which is much less compact in texture, lighter in the color of the groundmass, and shows a great many phenocrysts of hornblende.

All these andesites show a great tendency toward decomposition, becoming dull, more or less friable, and of a light reddish or purple color. Endogenous enclosures are quite common in the rocks of this group and will be described later.

Under the microscope the groundmass of these rocks is seen to be not typically hyalopilitic, but consisting of a glass base which is either colorless or brown according to the megascopic appearance of the rock, containing numerous microlites of plagioclase and augite with many magnetite grains and very much fine globulitic "dust." In the groundmass are also seen many larger plagioclase lathes, with small, stout, colorless augite crystals, and fewer small hornblende crystals, many of which are quite fresh and of a yellow-brown color, while others are altered to a dark opacitic mass either on the edges or completely. Here again while the distinction between the groundmass and phenocrystic plagioclase is easy on account of their diverse habits, as in the Stavro rocks, in the case of the augite and hornblende the line of demarkation cannot be sharply drawn, and the distinction is almost entirely a question of size, though the difference in the amount of alteration in the small and large hornblende crystals is of some assistance.

Augite occurs in not very large, usually well shaped crystals, showing the common planes of a clear and extremely pale brownish yellow color, so faint as to be almost colorless. In

some of the more decomposed specimens they are colored yellow or reddish brown on the edges. No pleochroism is to be observed, and the extinction angle is decidedly high, in many cases reaching or surpassing 45°. Hour-glass structure is not uncommon, though never well developed. Though the crystals are as a rule simple, yet twins, generally with the twinning plane *a* (100), are to be noted; and in some cases interpenetration twins, of two prisms crossing at angles of about 76° and the clinopinacoids being parallel. These apparently have the twinning plane *c* (001), and resemble the augite twins described by Elich[1] in andesites from Ecuador.

The crystals are frequently grouped in clusters of irregular shape, and with no definite arrangement of the component crystals, somewhat resembling in structure, but not mineral composition, the clusters of Judd's glomero-porphyritic structure.[2] These again sometimes assume the form of rings of augite crystals (sections of spheroidal shells), which surround a nucleus of clear, colorless substance which generally shows perlitic cracks and only rarely exhibits a faint double refraction. This is without doubt glass, and in the few cases where it acts on polarized light the effect may be caused by a state of strain due to the growth of the augite shell. Projecting into this glass nucleus from the inner edge of, and at right angles to, the augite ring, are small colorless or greenish prismatic crystals, which present all the characteristics of augite. They resemble the augite fringes often seen around enclosed quartz grains and may be of secondary origin.

The hornblende of these andesites belongs to the brown variety and megascopically much resembles the so-called basaltic hornblende, though the color is blacker and the surfaces more glistening.

Microscopically they are seen to be larger than the green

[1] REISS and STÜBEL. Reisen in Süd America. Das Hochgebirge, I. Rep. Ecuador, I. West Cordillers iii., atacatzo bis liniza von E. Elich. Berlin 1893, p. 157, Pl. iii., Fig, 4.

[2] JUDD. Q. J. Geol. Soc. XLII. 1886, p. 71.

hornblendes of the hornblende-andesites or than the augite crystals accompanying them, and to have been originally well shaped stout crystals, without the orthopinacoid. The color is a pale yellow-brown, with strong pleochroism; $\mathfrak{c}$ yellowish brown, $\mathfrak{b}$ yellowish brown, $\mathfrak{a}$ colorless, the absorption being $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. In some of the hornblende-augite-andesites of Mt. Pagoni an intermediate type is seen, of a greenish brown color, which, however, resembles more the brown than the green variety. The extinction angle of the brown variety is lower than that of the green, varying from 5°–6° 35′—a fact quite in accordance with the observations of Belowsky, to be mentioned later. Inclusions are not common.

This brown hornblende, as has been so often noticed, is decidedly prone to alteration. While most of the small crystals which occur in the groundmass are either quite fresh or only altered on the edges, the larger crystals, even the largest, which may be ten or many more times the diameter of these smallest ones, are entirely altered (or with only a small unaltered core) to a very fine-grained almost opaque, black mass of augite and opacite (magnetite) grains. The further stage of alteration to a more coarsely granular augite-magnetite aggregate is not generally seen in these rocks. Notwithstanding their alteration the original sharp outlines of the hornblende have been excellently preserved.

This alteration is so familiar and has been so often described that it is unnecessary to dwell upon it here at any length. One or two points call however for special mention. The presence of the small, unaltered crystals along with much larger altered ones points to the conclusion that not only were the large ones altered at a quite early period, but that the small ones were formed subsequently to, and under different conditions from, the alteration of the larger ones.

I observed also in many cases of juxtaposition between hornblende and feldspar that the presence of the feldspar had no effect on the alteration, this being as great at the surface of contact as along the free sides of the hornblende crystal. This differs some-

what from the observation of Küch[1] that hornblende in contact with microfelsitic groundmass was unaltered, while next to vitreous groundmass it had been altered, this being seen even in the same crystal.

A few words in regard to the difference between the brown and the green varieties of hornblende. Belowsky,[2] on the basis of some very valuable and interesting experiments of his own, puts forward the view that the brown is chiefly produced by alteration of the green "through the action of heat, in which oxidation was possible." Against this view must be brought up the fact that here in Ægina we meet with both varieties, but never in the same rock species. The green is characteristic of the *pyroxene-free* hornblende-andesites, and where this has undergone alteration, as in the case from Mt. Chondos, described on page 25, the resulting form of hornblende is quite different from the brown variety just described, which is the characteristic hornblende of the *pyroxene-bearing* andesites. This correlation of almost colorless pyroxene and brown hornblende, which is well established in the rocks before us (and, I may add, in the closely analogous augite-andesites of Smyrna and biotite-andesites of Pergamon), shows that the formation of the different varieties of hornblende is dependent on the different chemical constitutions of the magmas, and on the different conditions, which in one case determined the crystallization of the ferro-magnesian molecules as pyroxene and brown hornblende, while in the other they crystallized out as green hornblende, with or without biotite, and with little or no augite.

That the green hornblende on heating assumes the color and extinction angle of the basaltic hornblende is not to be denied, but in view of the facts above mentioned, and the vague and unproven character of the difference of heat conditions in the formation of the different varieties of hornblende, it is surely too much to infer from this fact that the brown hornblende is always derived from the green by alteration of the latter, and cannot have an independent origin and existence of its own.

[1] Küch. Op. cit. p. 55. Pl. V. Fig. 6.

[2] Belowsky. Op. cit. p. 37 ff.

It must further be remembered that the green hornblende was itself formed and existent in a magma at a temperature undoubtedly much higher than that of the simple Bunsen burner employed by Belowsky; but whether in the absence of oxygen or not we cannot perhaps say, though in view of the well established presence of water in most lavas and its probable dissociation at the high temperature of the liquid lava in the conduit oxygen may reasonably be supposed to have been present. At any rate, in the case of two lavas erupted under such similar conditions as those of Stavro and Chondos there is no ground for assuming that the latter was at a higher temperature than the former,[1] or that the one was oxygen-free and the other not. Again, it is difficult to explain by Belowsky's theory the presence in the same specimen of crystals of both varieties, which has been frequently observed, while if we grant to each variety a separate existence, this fact is easily explicable on the basis of the frequent presence of streaks (*Schliere*) in molten magmas, and their consequent want of homogenity in chemical composition.

The plagioclases of the andesites show the same difference between the phenocrysts and the groundmass crystals as in the preceding rocks. The phenocrysts are usually quite clear, and while glass inclusions, often with bubbles, are common and frequently zonally arranged, they seldom show such well developed net forms as have been described above. The phenocrysts show much zonal structure and many twinning lamellæ, which, giving extinction angles of 33° and 34°, show that they are of anorthite, while the smaller lathes, giving angles of 22° to 24°, are of bytownite.

Phenocrysts of biotite are not infrequent, and are in most cases entirely altered to an opacitic aggregate similar to the hornblende. Magnetite is abundant, but calls for no special remark.

Hypersthene-Andesites.—These rocks are characterized by the abundant presence of orthorhombic pyroxene, hypersthene, which

[1] As the Chondos rock seems to be more basic than that of Stavro, it is even probable that its temperature on eruption was less than that of the latter; this would also hold good for the brown hornblende-bearing hypersthene-andesites and the green hornblende bearing dacites.

is often accompanied by augite, occasionally to such an extent that it is difficult to decide whether a given specimen ought to be called a hypersthene-augite-andesite, or an augite-hypersthene-andesite. With one exception, however, it seemed better to group them all under the heading above, especially since the great majority of hypersthene-andesites elsewhere do carry more or less augite, while many augite-andesites are entirely free from orthorhombic pyroxene. The rocks richer in augite will be known as augite-hypersthene-andesite, while those which are quite free from, or very poor in, augite will be called hypersthene-andesite proper. The reason for making this distinction is the greater inasmuch as it corresponds quite exactly with the geographical distribution of the two varieties. The one exception mentioned above is that of a rock entirely free from hypersthene, which is hence a true augite-andesite, and will be described in its proper place.

In some of these rocks, notably in the products of the latest eruption at Kaimeni, hornblende is present in considerable quantity, and as the presence of this hornblende is correlated with structural and other characteristics, these specimens will be described later as hornblende-hypersthene-andesite.

The list of localities at which hypersthene-bearing and hypersthene-andesites occur has been largely increased in the last few years, and their occurrence here is not at all surprising when it is recalled that they occur abundantly at Santorini and Milos and at Erimomilos which are on the same volcanic fracture line. This point will be referred to later.

Hypersthene-andesite proper is found only on Methana, at the top of Mt. Chelona, at and above the acropolis of Methone, around the small harbor of Vathy on the west coast and at one point on the northeast coast. The augite-hypersthene-andesites make up the main mass of Mt. Oros and Mt. Kouragio on Ægina, while the augite-andesite proper is found at Agio Somatos near the Hellenic ruins. These sub-groups resemble each other so much and shade into each other so gradually that they may be described together.

Megascopically they are compact, fine-grained rocks of a rather dark, slightly bluish gray color, the groundmass showing to the naked eye comparatively few small phenocrysts of dull white plagioclase with, at Chelona, a few hornblende needles, and at Oros and Mt. Kouragio a very few rounded colorless quartz grains. They present, on the whole, a decidedly phonolite-like appearance, the resemblance being heightened by the lamellar structure seen on the top of Mt. Oros and at Agio Somatos, and by the sound which many of them give on being struck with a hammer, notably the rock from the south end of Mt. Kouragio. The augite-andesite of Agio Somatos differs slightly from the others in being rather granular in structure, and containing more slender hornblende needles. These rocks do not decompose readily and are quite fresh, except in the case of two specimens from Mt. Oros, which are reddish brown in color.

Under the microscope these rocks show an abundant, often hyalopilitic groundmass, with flow structure well marked; the glass base, which is clear and colorless, except in the Mt. Kouragio rocks where it is light brown, being in relatively small quantity. This glass base seems to be more abundant in the hypersthene-andesites than in the augite-hypersthene-andesites, in one or two of the latter from Mt. Oros the groundmass being almost holocrystalline, with only traces of glass, and in those from Mt. Kouragio the groundmass being rather basaltic with many lathes of plagioclase and hypersthene, and very little interstitial glass base.

The microlites and small crystals of the groundmass are mainly hypersthene, with fewer of plagioclase, many magnetite grains, and in the augite-hypersthene-andesites very many small, approximately equidimensional crystals of nearly colorless augite.

The small hypersthene needles vary in length from 0.02 to 0.1 mm., their diameter being as a rule about one-fifth of the length. They all have parallel extinction, show low domal or pyramidal terminations, and are generally cracked transversely. They are clear and almost colorless, of a very faint greenish

tinge, with feeble but marked pleocroism, ‖ ċ pale greenish gray, ⊥ċ pale yellow. The hypersthene is the most easily decomposable constituent of these rocks, perhaps owing to the large amount of FeO, and in the more altered rocks (such as those of Mt. Oros) they have almost entirely disappeared, and are only represented by red and brown rectangles and patches of ferrite, or other ferruginous decomposition products.[1]

The plagioclase lathes and crystals of the groundmass show few planes and are usually rectangular in outline. They are either single crystals or simple twins, very few showing multiple twinning lamellæ. As they possess extinction angles of 28° to 31° they belong to the bytownites richer in lime, or even to the anorthites.

A striking characteristic of the hypersthene-andesites proper is their extreme paucity in phenocrysts, especially of the ferromagnesian silicates. Plagioclase phenocrysts occur, but not abundantly, both megascopically and microscopically, but phenocrysts of pyroxene, hornblende or biotite are almost entirely lacking; a circumstance which, together with the facts that hypersthene is abundant in the groundmass, and that the small plagioclase lathes are apparently richer in lime than the phenocrysts, forms another occurrence, in addition to the many already noted, which are not in accordance with Rosenbusch's law that as crystallization proceeds the remaining magma becomes more acid.

Phenocrysts are, however, much more abundant in the other sub-group, and consist chiefly of augite in not well shaped, clear, and almost colorless crystals. Hypersthene in prisms up to 0.8 mm. in length also occurs. The presence of augite seems to have determined, or to be correlative with the presence of hornblende which is almost or quite entirely wanting in the hypersthene-andesites, but rather abundant as phenocrysts in the other group. Originally of a brown color it is invariably altered to an augite opacite aggregate, which is generally quite fine-grained and surrounded by an outer zone of colorless augite with some plagioclase.

[1] *Cf.* FELIX and LENK: Beitr. Geol. Pal. Rep. Mexico, Leipzig, 1890, I., p. 91.

In the Mt. Kouragio rocks, however, it is more coarsely granular and apparently little coherent, as the original crystal outlines are quite lost and the granular masses rounded and washed away by the moving magma.

The plagioclase phenocrysts are of good size and show many more planes than the smaller groundmass crystals. They seldom show twinning lamellæ and the one case where measurement was possible gave an extinction angle of 25°. They bear as inclusions small hypersthene and apatite needles and spots of glass. Some of them show a peculiar core composed of a micropegmatite of what may be either two different feldspars, or particles of the same feldspar, but oriented in two different directions.

In the rock which forms the small hill of the Methone acropolis there are present quite numerous phenocrysts of olivine which can also be seen with the naked eye. These are rather irregular in shape and often broken, though showing traces of crystal faces. They are colorless and quite fresh except on the edges, where they are generally colored bright yellow through incipient decomposition. Such an olivine-bearing hypersthene-andesite also occurs in one specimen from near Vathy Harbor, and from the west slope of Mt. Oros. The last specimen differs from the other rocks of the district in being of a pale brown color, very compact, with subresinous luster and with numerous phenocrysts.

Hornblende-Hypersthene-Andesite.—This has a special interest as it forms the material poured out by the eruption of *ca.* 250 B. C., and hence represents the latest eruptive product of the region. It is also represented by specimens from a loose block on Mt. Chelona and from near Agios Georgios on the northeast coast. The Kaimeni rocks are, however, of the most importance and the following description applies chiefly to them.

They are not very compact rocks, containing numerous pores and in some of the specimens assuming a quite scoriaceous character. They are highly porphyritic, showing, when fresh, a light gray, fine-grained, but dull and not very compact groundmass, with many phenocrysts of plagioclase and black hornblende,

very few biotite tables and still more rarely quartz grains. The scoriaceous specimens are decomposed and have become rather friable and of a dark reddish brown color. The specific gravity was found to be 2.44 in the freshest specimen.

Microscopically they show a hyalopilitic groundmass of colorless glass base with very numerous, almost or quite colorless, hypersthene and fewer plagioclase lathes. Larger, but still extremely small plagioclase and hornblende crystals, together with a few colorless augites, are also present in the groundmass.

The hornblende which occurs as large phenocrysts is generally prismatic, and of a brownish green color, quite fresh and free from alteration. It contains some inclusions of magnetite, plagioclase and a few biotites of large size and is itself inclosed partially by the largest plagioclase phenocrysts. These latter which, judging from the extinction angles on c (001) of 35°–38°, are anorthite, are quite fresh but contain many inclusions, chiefly of brownish glass with bubbles, and in one case of very many small flakes of biotite. A few phenocrysts of the latter are also seen, and good-sized grains of magnetite are abundant.

The hornblende-hypersthene-andesites from the other two localities much resemble the above, that from the top of Mt. Chelona differing chiefly by its more typical hyalopilitic structure, the absence of transition forms between the phenocrystic and groundmass crystals and the more vivid green of the hornblende.

Hornblende-Dacite.—This composes the two hills at Anzeiou and Kakoperato in the Oros District on Ægina which seem to be later flank eruptions of the main Oros outflow. The Anzeiou rock is light gray, rather compact and quite free from pores but rough in feel. The groundmass is fine-grained with numerous small hornblende needles. Phenocrysts are very abundant, chiefly white plagioclase crystals with some larger black hornblende prisms and many slightly pink quartz grains, generally rounded, but here and there showing a bipyramidal form, unaccompanied by an augite fringe.

The Kakoperato rock differs somewhat from the other, the phenocrysts which are the same as in the preceding being much

less numerous, though larger, and arranged often in lines of flow. The groundmass is very compact, of a darker, bluish gray color and sub-greasy luster, containing some hornblende needles. The enclosures in this rock, which are very numerous and striking, will be described later. With this Kakoperato rock must be classed the rock near Agio Vesili on the west coast of Ægina, on the ground of its general appearance, though no analysis of it was made and quartz grains are not nearly as abundant as in that just described.

Under the microscope the slides of these occurrences show much the same features.[1] The hyalopilitic groundmass is largely predominant, the glass base being colorless (with no perlitic cracks), and the microlites (which are largely feldspar) showing a beautiful flow structure, but being more abundant in the Kakoperato than in the Anzeiou specimens. Crystals of hornblende and plagioclase and grains of magnetite are also rarer in the groundmass of the former while abundant in the latter. Many of the microlites and lathes of feldspar in the Kakoperato dacite are untwinned and show parallel extinction which points to the presence of orthoclase, belief in which being strengthened by the comparatively large quantity of K_2O shown on analysis. It is noteworthy that neither in these nor in any of the other dacites was quartz met with as a groundmass constituent.

The phenocrysts are chiefly hornblende and plagioclase, only a few quartz sections being found in the slides. Magnetite is present, though not abundantly, in rather large, well shaped grains which must be classed rather with the phenocrystic than with the groundmass constituents.

The hornblende which occurs only as phenocrysts is in small but well shaped crystals, often broken. In color they are brownish green (that of Agio Vesili is greenish brown) and quite fresh and unaltered. Rare inclusions of plagioclase, augite, and magnetite are found. In general character and habit they much resemble the hornblendes of the Stavro rock, though the color is more inclined to brown.

[1] On the whole the slides much resemble those of the dacite from Lassen's Peak in my possession.

The large plagioclase phenocrysts are quite fresh and clear and many show a "network" core of glass. Twinning lamellæ are not very common, and, as the angles observed were small, the phenocrysts are referable to labradorite, though in some cases they seem much more basic.

The few quartz sections are rounded and irregular, perfectly clear but much cracked and with few inclusions of glass. One small perfectly hexagonal section was seen. A few small colorless prismatic augite phenocrysts were noted as well as some dark green biotite tables, one of which contains a colorless zircon.

Hornblende-Hypersthene-Dacite.—It would be more in accordance with Zirkel's definitions to call these rocks quartz-pyroxene-andesites since he reserves the name dacite for the more acid or quartz-bearing hornblende or biotite-andestites.[1] On the other hand Rosenbusch[2] does not put these limits on the dacites, but includes among them very acid or quartz-bearing pyroxene-andesites. I am inclined to favor his view since the presence or absence of quartz or superabundant silica seems to me a consideration of much more weight than the nature of the ferro-magnesian silicate, and this, together with the presence of *green* hornblende in the most typical specimens, has decided me in giving them the name they here bear; they being called as they are owing to the greater abundance and importance of the hypersthene over the hornblende, none of the latter appearing as a groundmass constituent.

These rocks are the most abundant of any species on Methana, most of the mountain masses around Mt. Chelona being formed of them. Specimens were collected and examined from near Vromo, from the ridge south of Mt. Chelona, Mt. Chorsa to the northwest of Chelona near Panagia on the northwest coast, and from the neighborhood of Kosóna, both near the town and between it and Mt. Chelona; and, further, my notes show that the rock along the coast between Kosona and Vromo

[1] ZIRKEL. Op. cit. II., p. 569.

[2] ROSENBUSCH, Mikr. Phys. II., 1887, p. 634.

Limni are the same as at the former place; so that it is seen that the whole southern part of the peninsula (with the exception of the district around Methone and Megalo Chorio), with much of the northwest, north and east are of these rocks.

These do not show as much quartz as the other dacites, that from near Panagia especially being quite free from it, though its high silica content (64.83 per cent.) shows that it belongs here. Megascopically they much resemble the dacite of Anzeiou, being not very compact, light-gray rocks with very numerous phenocrysts of plagioclase and hornblende, and fewer colorless or pinkish quartz grains. The Panagia specimen is much more compact and finer grained than the others, and phenocrysts are smaller and less abundant. Endogenous enclosures are not rare, especially in the rock about Kosona.

Under the microscope there are seen to be three distinct types. The Kosóna specimens resemble much the hornblende-dacite of Anzeiou, the groundmass being typically hyalopilitic with colorless glass base. The hornblende is bright olive-green and perfectly fresh. Hypersthene, besides composing the great majority of the groundmass microlites, occurs in good-sized prisms as phenocrysts, which show all the optical characters already mentioned. Magnetite also occurs in large and small grains, but is rare as a true groundmass constituent. Some small colorless augite crystals are also seen. The plagioclase, which occurs chiefly in large poorly shaped phenocrysts, many with glassy "net" cores, shows many twinning lamellæ; and the extinction angles of 25° and even less show that it is a bytownite rich in soda. They contain very many apatite needles. Biotite is very rarely seen in the slides, one large, clear, greenish gray prism being much corroded, and altered at the edges to a very coarse granular mixture of augite, plagioclase and magnetite. This alteration had chiefly taken place in the zone of the prisms and pinacoids, the basal plane being sharp and quite fresh.

The second type is that presented by the specimens from the southern and western parts of Methana (with the exception of the Panagia specimen). These are characterized by a very dusty

brown groundmass, the base being colorless glass which is filled with an infinite number of grains of "dust" and small microlites, generally short, stout and rarely long (as usual). These microlites are chiefly augite and hypersthene, little plagioclase being represented. Besides these microlitic constituents there are small lathes and rectangular sections of plagioclase, small augite and hypersthene crystals and some magnetite.

The hornblende phenocrysts in these rocks are yellowish brown in color, and often altered on the outer edges to an augite opacite aggregate. Hypersthene crystals are common, but not as large as in the preceding type. In one specimen, which shows signs of decomposition, they are either entirely or partially changed to rusty or reddish brown secondary products. The plagioclase, whose sections are generally rhombic or rectangular, is similar to that of the preceding. A few clear, corroded and cracked quartz grains are seen.

The third type is only represented by the Panagia specimen, which also differs from the others megascopically. The groundmass here seems to be chiefly microfelsite with little or no glass. In the microfelsitic base are many minute magnetite grains, and flecks and microlites of feldspar, part of which may be orthoclase, as indicated by the parallel extinctions. As the percentage of K_2O is small, however, it seems more probable that this is labradorite, or oligoclase. Hypersthene is not abundant in the groundmass.

The phenocrysts are not numerous and consist of brown hornblende, altered as before described, with some plagioclase and hypersthene, which call for no special comment. There are numerous spots of tridymite, which seem to be an essential and not a secondary constituent.

It must be remarked that the position of this Panagia rock is an uncertain one on the whole, and I would call it a trachyte were its percentage of K_2O not so very much lower than that of any other trachyte analysis.

Biotite-Dacite.—This dacite, whose occurrence is described on page 806, Vol. II., is only found on the mainland, and all the

specimens examined come from the railroad cutting near the hamlet of Kolautziki. A short petrographical description by Dr. R. Lepsius, which will be referred to later, will be found on page 604 of Philippson's "Peloponnes."

The specimens show a fine-grained, but not very compact, very light gray or light brown groundmass which contains many minute black biotite flakes and feldspar and quartz grains. In this are thickly scattered larger phenocrysts of colorless feldspar, small biotite tables and grains or bi-pyramids of pink or amethystine quartz, which on the weathered surfaces have entirely lost their color. These crystals do not show much definite arrangement in lines of flow.

Under the microscope they show a highly vitreous groundmass traversed by numerous perlitic cracks, and containing few microlites, but flow streaks of brown or greenish dusty matter. In the groundmass also lie many small flakes of olive-green biotite, with some small plagioclases and still fewer small quartz grains which are arranged in lines of flow. Hardly any magnetite is present.

The phenocrysts are of biotite, quartz, and feldspar. The first are not very large hexagonal tables, olive-green when fresh, but banded or mottled with reddish brown in the decomposed specimens. They are very poor in inclusions, only a few plagioclases and zircons being thus met with. Clear, colorless quartz grains are common, generally with rounded outlines, though occasionally showing crystallographic boundaries. They are quite free from inclusions, no glass being noted and only a few colorless zircons.

The feldspar phenocrysts which contain few inclusions of glass, biotite, and zircon in almost every case are plagioclase, though many of them are simple crystals, and twinning lamellæ are rare, one case giving angles which indicate labradorite. Though Lepsius makes the prevailing feldspar out to be sanidine, and hence calls the rock a "quartz trachyte," my own observations fail to confirm this. Though the crystals are generally simple and clear and hence look like sanidine, careful

search failed to diclose more than a very few which gave parallel or approximately parallel extinction. Moreover, the chemical composition of the rock is that of a typical dacite, and not at all that of a quartz-bearing trachyte or rhyolite.[1] The percentage of K_2O (1.66) is much too low for a rhyolite as rich in orthoclase as Lepsius makes out the rock to be. The percentage of CaO (2.98) again is much higher than that shown by any other rhyolite analysis, while quite in accordance with other dacite analyses. It is true that it is the lowest lime percentage of any of the rocks of the district, but this is quite in accordance with the comparative scarcity of feldspar, and its position in the albite-anorthite series. For these reasons the feldspar is held to be a plagioclase, and the rock is consequently a dacite.[2]

Tuff.—Only two specimens of this fragmental rock were collected. That from the west end of Mt. Chondos is light gray in color, rather finely granular, very friable, and shows evidence of stratification. Under the microscope it is seen to be composed of fragments of fresh olive-green hornblende, plagioclase crystals, magnetite grains, a few colorles augite crystals, and much microlitic groundmass with colorless glass base, patches and streaks of brown dusty material being very abundant, and there being no definite order in the arrangement of the above fragmentary constituents. No remains of organic beings, either animal or vegetable, were to be seen, and the specimen is evidently a tuff of the light gray hornblende-andesite deposited subaërially.

The brown compact tuff from farther east, near the top of the Chondos ridge, offers more points of interest. Megascopically it is very compact and fine grained, light brown and with a subgreasy luster. In this main mass are many rounded enclosures of a gray porphyritic hornblende-dacite, showing hornblende, plagioclase, and quartz phenocrysts, and resembling the dacite of Kakoperato.

Under the microscope the tuff shows a brecciated structure

[1] *Cf.* Analysis 15, in Part III.

[2] ZIRKEL (Op. cit. II. p. 258), on the authority of Lepsius, classes these rocks, as well as the hornblende-andesite of Poros, with the rhyolites.

composed largely of small angular fragments of the hornblende-augite-andesite of the Monastery district, with pieces of the brown hornblende, colorless augite, and plagioclase that occur in these rocks, this fragmentary material being cemented by a clear, colorless isotropic substance. Since chemical analysis (*cf.* No. 16, Part III.) shows that this tuff is very acid, containing 70.81 per cent. of silica, and since the rock of which the breccia fragments are composed contains only about 55 per cent. of silica, it seems certain that this glassy cementing substance is a form of amorphous silica, such a silicification of eruptive rocks being a not at all unusual phenomenon. This tuff is also, like the preceding, of subaërial origin. Through a misunderstanding no slide of the gray enclosures was made, but, as they present the megascopical characteristics of the Kakoperato dacite, they may be safely classed as analogous to these, though an analysis giving 71.49 per cent. of silica shows that they also have been subjected to the silicifying process.

The only other eruptive rocks found on Ægina were a block of a hard, greenish, aphanitic hornfels-looking rock which on examination proved to be a porphyry; a small rounded loose block of a coarse-grained biotite-granitite, with rather gabbro-like structure, and which probably came from one of the Cyclades as ballast; and many rounded fragments of white pumice found on the beaches of Ægina and Methana which undoubtedly have floated from Santorini, as they present the characters of this pumice, which I found on my visit there floating in large quantities in the inner bay of the island group.

HENRY S. WASHINGTON.

(To be continued.)

LAKE BASINS CREATED BY WIND EROSION.[1]

In various parts of the Great Plains lakelets are somewhat abundant. At the north some of them occupy hollows in the uneven surface of the drift; elsewhere they are imprisoned by the unequal heaping of sand in dunes.

Those of a third class are independent of drift and dunes, and their explanation is not so readily apparent. They are so shallow that one may wade across them in any direction. They have no outlets and no permanent inlets. Their catchment basins are small. Ordinarily their basins interrupt divides between stream valleys, and they often rest on the highest tables of their vicinity. They are not permanent, but appear and disappear as storm and drought alternately prevail. Some basins are ordinarily dry, holding water only for a few days or weeks after a thunder storm. The lakes of others are approximately perpetual, disappearing only after a succession of dry seasons.

During the summers of 1893 and 1894 I rode extensively through a district in the Arkansas basin where these lakes are somewhat abundant; in one rectangular tract containing less than 1000 square miles twenty were noted. Various hypotheses as to their origin were considered, and at the end of the first season wind action was preferred, but less because its process was understood than because each other suggested hypothesis seemed barred by some insuperable obstacle. In the second season, however, some allied phenomena were observed which seemed to throw light on the subject and served to strengthen the hypothesis of wind action.

The rocks of the country include a sandstone and two limestones which constitute the crests of the uplands, but the greater part of the surface is occupied by shales. The shales sustain a scanty growth of grass, with here and there a shrub and, more

[1] Read to the Geological Society of America, December 27, 1894.

rarely, a few bush-like junipers. Their grade profiles are in general the typical products of subaërial degradation, convex upward on the divides and elsewhere gently concave. Interrupting these simple and familiar slopes there were found a few saucer-shaped cavities whose clean, smooth surfaces suggested at once their wind-swept character. They are almost wholly devoid of vegetation, and the shale from which they are carved is directly exposed without the intervention of residual or overplaced material. Three of them occupy a hillside sloping westward, so that the prevalent wind blows up hill. A part of the material excavated from these is deposited at their upper edges, and in the case of the individual most closely examined, has accumulated to such depth as to constitute a raised rim, deflecting the general drainage of the slope so that it passes around the hollow. The hollow itself is drained through several channels intersecting its lower edge. Rain and wind thus seem to be contesting for the mastery, and should the wind ever so deepen the saucer that it can contain without overflow the rain which falls upon it, a permanent lake basin may result. In another instance a small saucer is hollowed from an eastward slope, and here a clump of junipers standing at the lower edge has, by checking the wind, so aided the deposition of the detritus that the rim has been raised higher than the interior of the hollow and a temporary pool is the result. In yet another instance the hollow is carved on a southerly slope, and so deeply that it would pond the rainfall were it not tapped by a strong drainage line traversing the general slope at its eastern edge.

In each case the normal slopes of the country are sharply interrupted by the features of the saucer, whose steep sides descend quickly to a relatively level bottom. The wind seems to have first swept out a few feet of disintegrated and residuary material, and then been checked by the firmness of the unweathered shale in which it can work no faster than the rock is disintegrated by frost and kindred agencies.

In four of the five instances the rock attacked is a dark shale which is naturally almost sterile, so that vegetation on its surface

is exceptionally scanty unless it is coated by an overwash of other material. This relation suggests that the condition essential to the initiation of the excavation is the absence of vegetation. The function of vegetation as a defender of the soil against ravages of the wind is already familiar, and it is easy to understand that whenever a tract of land in an arid region is deprived by some accident of its vegetal covering, the wind may at once become an important factor in its sculpture, clearing away all disintegrated material and, if the tract is small, producing a hollow. If the hollow is so related to the slopes and drainage that it can gather water but will not be filled to overflowing, a permanent basin may result, for alternate flooding and drying will tend to keep the bottom of the hollow barren so that whenever it is dry the wind can continue its work. I believe the lake basins in question to have been created in this way.

In their present condition it is evident that they are naturally subjected to antagonistic processes dependent on the wind. While they contain water they receive dust from every gale that sweeps across the country, and the sediment thus accumulated, which is of no inconsiderable amount, tends, of course, to fill and thus obliterate them. When they are dry the wind resumes its erosive action and their bottoms are degraded. Professor Chamberlin has suggested an organic agency which also must constitute an important factor. In a region where springs and streams are rare the lakes are much resorted to by herds which, wading into the water to drink, carry away a coating of mud upon their feet and legs. The greater part of this mud is lost before they return, so that in this accidental way the beds of the lakes are steadily excavated and their margins enlarged. Horses and cattle sometimes increase their load by lying down in the mud, and their predecessor, the buffalo, is said to have the same habit.

With the pools called buffalo wallows I have little personal acquaintance, and I am not prepared to say whether their basins are initiated by the wind, or constitute an independent class with purely bovine origin.

G. K. GILBERT.

ON CLINTON CONGLOMERATES AND WAVE MARKS IN OHIO AND KENTUCKY.

WITH A RÉSUMÉ OF OUR KNOWLEDGE OF SIMILAR OCCURRENCES IN OTHER SILURIAN STRATA OF THESE STATES, AND THEIR EVIDENCE UPON PROBABLE LAND CONDITIONS.

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Lower Hudson, at West Covington, Kentucky.
Upper Hudson, near Winchester, Ohio.
Observations by Nelson W. Perry and Joseph F. James, near Oxford, Ohio.

First record of the occurrence of pebbles in the Clinton of Ohio, by Professor Orton.—It is almost twenty-five years since the discovery of pebbles in the Clinton of Ohio was announced. The value of the discovery for determining the physical conditions which must have attended the deposition of this group was at once recognized. The Cincinnati anticlinal axis was believed to have been in existence as a land area in Paleozoic times, and the occurrence of pebbles towards the eastern border of the axis, the supposed shore line of Paleozoic times, seemed strong corroborative evidence of this view, and was believed to fix the

date of the initial rise of the axis, at least approximately. Curiously enough, in spite of the acknowledged importance of the discovery, Professor Edward Orton, the discoverer, and the now venerable state geologist of Ohio, seems to be the only geologist who ever visited the original pebble locality at Belfast, in Highland county, and so all references to the pebbles made by other writers are based upon his work. For that reason his original statement, made in the report of the Ohio Geological Survey for 1870, page 270, is here reprinted. Those parts of the quotation which recent discoveries seem to disprove are italicized:

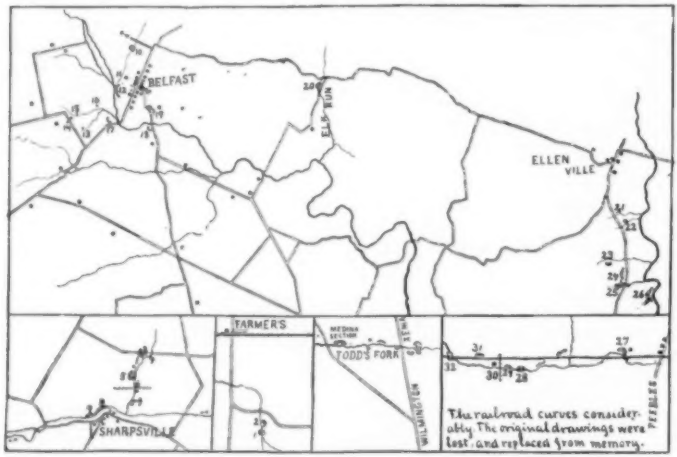
"A bed of limestone conglomerate, several feet in thickness, occurs near the *base* of the (Clinton) series in the southern part of the county. But a single exposure of the conglomerate has yet been noted. This is found one mile due west of Belfast, on the Belfast and Fairfax road, on the land of Charles Dalyrymple (localities 13, 14, and 15, of this paper).

"The pebbles that compose the conglomerate *appear to have been derived from the Blue limestone or Cincinnati rocks.* The conglomerate is also fossiliferous, well-worn forms of ancient life being incorporated with it. The fossils can be referred *either to the Cincinnati or* Clinton group, as they consist of forms that are common to both formations, viz., cyathophylloid corals of the genus Streptelasma and the remarkable fossil, Orthis lynx—a bivalve shell of immense vertical range, as is shown by its occurrence in the Trenton, Hudson (Cincinnati), Clinton, and Niagara limestones of the Lower and Upper Silurian ages, successively. It seems more probable, however, that the fossils in question were derived from Clinton seas rather than from the waste of rocks of a previous age.

"The occurrence of this conglomerate attests the existence of land near by—the shores of which were wasted by the sea, and the water-worn and rounded fragments of which were re-deposited on the floor of the sea. Since the first systematic study of the geology of the Mississippi Valley, proofs have been accumulating that a Silurian island stretched northeastward from Nashville, towards and beyond Cincinnati. Highland county furnishes its full quota of facts as to the existence, and as to certain of the boundaries of this ancient land. Other facts will be adduced that bear upon this point in the description of the remaining formations of the county. The date of the uplift of this island is approximately determined by the fact already quoted—as land at the westward is found in existence *early in the history of the Clinton.* This folding of the crust, then, that transformed a portion of the ancient sea bottom into dry land, probably occurred about the close of the Lower Silurian

time, and it seems also safe to say that it not only marks the date but *furnishes the producing cause of the change in the formation that then took place.* The Medina shales may be referred to sediments that settled in seas, disturbed by igneous agencies—the long continued life of the preceding periods being exterminated in this region by the shallowing waters, as the low mountain chain emerges."

The change in formation, to which reference is made above, is that from the alternating limestones and clays of the Cincin-



Sketch maps of localities referred to in this article.

nati group to the shales of the Medina. Volcanic disturbances sufficient to keep the sediment of the sea in commotion, are hardly necessary to account for the change in the lithological character of the two formations.

Former observations by the writer, based upon Professor Orton's material.—Some years ago Professor Orton kindly placed at the disposal of the writer the pieces of conglomerate which had come from the original locality near Belfast. At that time it was noticed that the fossils contained in the cement among the pebbles were all of Clinton age, and not a single species of Cincinnati group affinities was found. Even in the case of Orthis lynx it was the Clinton form, and not one of the Cin-

cinnati group forms, which had been found. The pebbles of the conglomerate fragments collected by Professor Orton, were unfossiliferous, though fossils have been found recently, as described below. The lithological appearance of the pebbles was unlike that of any of the limestones known from the upper part of the Cincinnati group in Ohio.

It seemed therefore that some of the statements made in the original publication needed re-investigation, before they could be considered a safe basis for conclusions as to the probable physical and geographical conditions which obtained in Clinton times. A week was therefore spent in Clinton, Highland, and Adams counties, and sufficient material was found to disprove some of the original statements and to shed quite an additional amount of light upon the problems involved.

The original material is given in the following pages in full. Abstracts of pertinent observations made by other writers are also presented. Those who are more interested in the conclusions at which we have arrived, than in the facts upon which the conclusions are based, will find the former concisely presented at the end of this article.

PEBBLES AND WAVE MARKS IN THE CINCINNATI GROUP.

Observations of the Kentucky Survey.—In order to understand the physical conditions which prevailed during the Clinton epoch in Ohio, it is necessary to study this problem in connection with conditions existing both before and after this epoch. Since the central counties of Kentucky are also involved in the Cincinnati anticlinal axis, any facts which they afford will also be of interest. The following facts are collated from the more recently published reports on the geology of the various counties. With the exception of the report on Marion county, by W. T. Knott, and that on Clinton county, by R. H. Loughridge, these reports are all from the pen of W. M. Linney.

Trenton.—In Garrard county some of the layers are very irregular in their bedding, and some show wave marks. In Clark county the irregular stratification sometimes amounts to

cross-stratification, and at one locality great wave marks are found. Near the top of the Trenton are often seen rounded pebbles of limestone distributed in thin beds for a number of miles. They are mentioned from Garrard, and also from Clark and Montgomery counties.

Lower Hudson.—These beds are considered by Mr. E. O. Ulrich as being in large part equivalent to the Utica. Mention of wave marks is made from the following counties: Shelby, Spencer, Washington, Marion, Mercer, Garrard, Madison, Clark, Montgomery, Bath, Fleming, and Mason. The wave marks occur in the upper beds of this division. In Mercer county they are stated to occur 140 to 170 feet above the base. Their occurrence in the *upper* beds is more or less directly inferred from statements made with reference to these layers in Spencer, Washington, Mercer, Garrard, Madison, Bath, and Mason counties, and this is presumably their horizon also in the other counties. Cross-stratification occurs in the upper beds in Mason county.

Rounded limestone pebbles are stated to occur only in the case of one county, Washington. Here the lowest layer of the Lower Hudson is said to be about one foot in thickness, and to contain usually some rounded limestone pebbles. The occurrence of pebbles in Clark and Montgomery counties seems to be warranted by the following statement made, under the title of "Disturbances in Clark and Montgomery," in one of the reports: "In the Lower Hudson beds, where the alternations of hard limestones and shales are so constant, the intervals were produced by corresponding changes of condition, and in these hard layers are sometimes seen large pebbles of limestone, which have been worn until half round and then consolidated with finer material." In this case no particular horizon is mentioned.

Middle Hudson.—Wave marks are mentioned from Nelson, Washington, and Mason counties. In Washington county they are said to occur at the base. Those from Mason county are not located, and the reference to them is suspicious, as though the wave marks belonged to the well-known waved beds of the

Lower or possibly even the Upper Hudson, rather than the Middle division, under which the reference happens to occur.

Upper Hudson.—Cross-stratification occurs in the lower beds in Clark county; it is said sometimes to resemble large wave marks. The same conditions seem to occur also in Montgomery county. Wave marks occur in Oldham, Lincoln, and Fleming counties. Their position in Oldham seems to be somewhere beneath the top; in Lincoln they are found at many horizons; in Fleming they are located near the top of the series. In Spencer county indurated clay balls are found in the earthy limestones and shales near the top of the Upper Hudson. Under "Disturbances in Clark and Montgomery Counties" rounded pebbles of limestone are said to occur in some of the strata of the Upper Hudson.

Observations by E. O. Ulrich.[1]—At the base of the Lower Hudson there is generally a layer of limestone, one foot or so in thickness, which usually contains some rounded limestone pebbles. No localities are given, but Mercer, Boyle, and Washington counties are mentioned in the preceding sentence, and the occurrence of these features here and in other counties of central Kentucky may be inferred. See, for instance, the reference to a similar layer at the same horizon in Washington county, given above from the Kentucky Survey. In West Covington opposite Cincinnati, and about a mile west of the mouth of the Licking, the conglomerate occurs, which is to be more fully described, just below, from personal observations made in company with Mr. Ulrich. This locality belongs to the Lower Hudson, or the Utica of Ulrich. It is described by Professor N. S. Shaler in one of the earlier reports of the Kentucky Geological Survey. The waved-layers, which occur at several localities near Cincinnati, are correlated with the wave-marked layers so frequent near the top of the Lower Hudson in the other counties of Kentucky (Am. Geol., 1888, page 314).

In Washington, Boyle, Lincoln, Garrard, Madison, and Clark counties, the strata belonging to the top of the Middle Hudson and the bottom of the Upper Hudson are decidedly arenaceous,

[1] American Geologist, 1888, May, pages 308–310.

this feature being much more pronounced and of greater extent in southern Kentucky than in Ohio and Indiana. In fact, some of the lower portions of this series may with truth be called sandstones.

Observations of Dr. John Locke at West Union; Upper Hudson.—The locality is twelve miles a little east of south of Elk Horn creek, near a house known as Treber's at the time of Locke's report (Geol. Surv. Ohio, 1838, p. 246, and plate 6), in the bed of Lick Run. It is about four miles northeast of West Union, as nearly as can be determined from the report. Here, about fifty-five feet below the level of the Clinton, for a distance of 400 feet, wave marks occur in the upper Cincinnati group beds, with crests two to three feet apart, and two to three inches above the troughs. According to Locke they may be traced at about the same horizon for miles.

Observations of Professor Orton.—In Vol. I. of the Ohio Survey report, page 377, Prof. Orton mentions that Locke noted the wave-marked layers in the upper beds of the Cincinnati group, and then states that they are even more characteristic of the lower beds (the Lower Hudson of Kentucky reports) as shown in the river quarries of Cincinnati, or in the 100 feet that are there exposed. These wave-marked layers are said in every case to be overlain by shales.

OBSERVATIONS BY THE WRITER.

West Covington, Kentucky (Lower Hudson, or Utica of Ulrich).—Opposite Cincinnati, halfway between the Chesapeake and Ohio and the Cincinnati Southern railway bridges, opposite house No. 31, along the road skirting the river front, nearly at the top of the section exposed along the Ohio river is a well stratified, sandy-looking limestone layer, in places almost two feet thick, which can readily be traced for a considerable distance along the river front. Over this lies a layer composed chiefly of coarse crinoidal remains but containing also many bryozoan fragments, and some brachiopods. The crinoidal layer is about twenty inches thick. Its chief interest consists in the fact that

it evidently lies upon an eroded base, the underlying sandy-looking limestone having suffered more or less marked erosion previous to the deposition of the crinoidal layer. Owing to the marked stratification of the sandy limestone, the irregular erosion of its upper surface is readily observed, and the crinoidal layer is seen in places to descend considerably below the original level of the sandy layer. In some places the sandy limestone has been cut through so that the crinoidal bed rests upon the bed below the sandy limestone, but in the stretch examined along the river front the erosion seems to have been confined chiefly to the sandy layer and rarely extends to the layer beneath. Nothing could better express the limited vertical range of this erosion. In the crinoidal bed occur many fragments evidently derived from the sandy layer immediately beneath. Some of these fragments are of considerable width, slabs as long as two and a half feet having been seen inclosed in the crinoidal layer. The thickness of these fragments rarely exceeds four inches and is usually less. One slab of sandy limestone must have been at least five feet long, but this was exceptional. The usual length varies from four to seven, at times twelve inches, and the thickness varies from one to two inches. The edges are usually more or less rounded, but not to the same extent as are the pebbles of some of the Clinton conglomerates. Many of these pebbles occur near the base of the crinoidal layer; fewer are found in the central parts of this layer, but quite a number occur again, in places, at the top. It is very evident in this case, that the pebbles could not have been derived from a distant source, but must have been carried to pockets and depressions already formed in the sandy layer, while other parts of the same layer, at some point in the more immediate vicinity, were suffering erosion. Occasionally inclusions are found which were not derived from the sandy layer beneath. In one case, at least, a fragment of a coarsely crinoidal rock was included in the crinoidal layer; it was very similar to the inclosing rock, but its lines of stratification had a different angle. Rounded chunks of a clayey substance at present hardened, very fine-grained, and yellowish in color,

also occur; in places, plentifully; almost always near the top of the crinoidal layer, rarely towards the middle, and never at the bottom. They evidently were derived from a slightly greater distance than the sandy pebbles, but similar clayey rocks occur abundantly just above the crinoidal layer in the present section, and it does not seem necessary to imagine derivation from any considerable distance, since rocks having this lithological character may have occurred at a lower horizon not far off. The top of the crinoidal layer occasionally shows a heaping up into ridges or wave marks. Wave marks are, however, more frequently and better shown in the layers just below the sandy bed. More frequently these wave marks are associated with irregular ripple marks making it impossible to determine the direction of the markings. In a general way they may be said to run slightly east of north, but the wave marks are hardly sufficiently well oriented or distinct to make it worth while to draw conclusions from the same. The crinoidal layer frequently shows bedding, and in that case, the stratification lines usually incline strongly to the west, giving rise to a sort of cross bedding, when seen in conjunction with the stratification planes above and below. After having studied this layer, it is easy to understand how the pebbles in the Cincinnati group at Elk Horn, east of Winchester, and in the various Clinton conglomerates, could readily have been derived from the layers immediately beneath.

Winchester (*Upper Hudson*).—Elk Horn creek is crossed by the Cincinnati, Portsmouth & Virginia railroad about a mile and a quarter east of Winchester. This region is about 10 miles west of Peebles, and 10 miles southwest of Belfast; it is 39 miles a little east of south from the Todd's Fork locality. The trestle crossing the creek is about 75 feet high. Down the creek from the bridge is a magnificent exposure of wave-marked Cincinnati rock. The highest hills around Winchester, and also in the direction of Elk Horn and Brush creeks, show Cincinnati rocks, so that this exposure must lie at least 60 feet beneath the level of the Clinton. The wave marks are exposed for several hundred feet along the bed of the creek below the bridge. The crests

run north and south, are often three inches above the troughs, and are usually about 30 inches apart. Plenty of fossils occur just beneath the sand forming the wave ridges themselves, and they protrude through the same. On going down the stream lower horizons are met, and wave marks are also found at these lower levels. Farther down stream the wave marks run north 50° west and are not so fine as those first described. Still farther down stream are plenty of good pebbles caught up in the layers beneath the wave marks. The pebbles are often six, and occasionally eight and ten inches in diameter. They evidently were derived from the sandy, stratified, less fossiliferous beds of practically the same age which occur immediately beneath. While there was not found the same direct evidence of the derivation of these pebbles from other localities in the immediate vicinity, as opposite Cincinnati, this was probably due chiefly to less favorable exposure, those at Elk Run occurring chiefly in the creek bed, and those at West Covington being exposed on the steep banks of the Ohio in almost vertical section. While the pebbles were, as a rule, not richly fossiliferous, yet owing to their great abundance their identity could be readily established. All fossils found belonged to the horizon of the general matrix in which they were inclosed, showing their derivation from rocks of but slightly lower horizon.

Below the first house on the west side of the creek very good wave marks are again seen running north and south for a considerable distance. Farther down are others less good but distinct, running north 30° west. Within half a mile of the bridge, farther down, opposite a house on the east bank, plenty of pebbles occur in the rock. Some of these pebbles are slabs 16 inches in diameter, and about an inch to an inch and a-half thick. Just below, the wave marks run north 20° west. At a very considerable distance down the creek are loose slabs containing pebbles of moderate size, two to three inches in diameter. Farther down are poor wave marks, the usual distance apart and running north 45° east. Just below these are good wave marks running north 20° east. Some distance beyond this, Elk Horn

creek enters into Brush creek. It will be noticed that the good wave marks were those running north and south or more nearly in this direction; those running more northeasterly or northwesterly were poor. This probably means that the strongest brunt of the waves and freest exposure to the sea lay directly westward at this point. Going up Brush creek, at a locality not far distant from the junction of the Elk Horn creek a layer showing wave marks was found. These were not recorded, but are believed from memory to have run north 30° west.

Observations by Nelson W. Perry and Joseph F. James.—Wave marks and raindrop impressions occur at Smiley's dam on Four-Mile creek, near Oxford, Ohio, at a level 600 feet above the Mt. Pleasant beds. On the Little Four-Mile creek, at Ridenour's Mills, wave marks occur, going up stream. Mud-cracks are found in Dearborn county, Indiana, 600 feet above the Mt. Pleasant beds. These occurrences probably belong therefore to the Upper Hudson of Kentucky geologists.

AUG. F. FOERSTE.

(To be continued.)

GLACIAL STUDIES IN GREENLAND. III.

Coast Glaciers between Disco Island and Inglefield Gulf.

From the southern extremity of Greenland to the vicinity of Upernivik the ice-cap lies so far inland as to be but rarely and imperfectly seen from a coasting vessel. Here and there it forms the sky line between the mountains, and at intervals tongues push down the valleys to the inner coast line, but only such fragmentary views are offered to the passer-by. Even for a degree and a half beyond Upernivik, little may be seen of the interior ice-field, though nothing but a coastal fringe of islands intervenes. The Devil's Thumb, that grewsome landmark of the navigator, which stands over against the dreaded ice pack of Melville Bay, must be passed before the border of the great ice-field comes fairly into view.

It may be recalled that from Cape Farewell to the Devil's Thumb the coast has a mountainous aspect interrupted at intervals by lower tracts of fluent contours. Its general expression is harsh and rugged. Patches of snow and local glaciers give it an Arctic aspect; still it is more nearly ice-free land than an ice-field. It is a black-and-white border to the great white interior. Near Upernivik this border becomes reduced to a fringe of mountainous islands. These disappear near Lat. 74° 30′, and the great ice cap comes out to the coast and by its precipitous ice-walls forms the sea border. The Devil's Thumb, situated on one of the most northern of these bordering islands, becomes the sentinel of the transition from the one type of coast to the other. It is a columnar monument of rectangular aspect surmounted by a more slender column, not altogether unlike the combination of the Auditorium tower, if a local comparison may be permitted. A resemblance to his majesty's opposable digit would never have occurred to me, but this may be due to a lack of personal

acquaintance. There was certainly also a lack of suggestive associations; for as a relatively slender column standing only a few miles from the edge of the great ice sheet it awakens in the glacialist thoughts lying in quite opposite thermal relations. What does this column so situated signify respecting the former extension of the ice? There are better reasons than the temperature associations of his majesty for thinking that the ice may never have passed over the Thumb since its isolation. Without fuller knowledge, however, there is an open alternative between the view that exfoliation has developed the monument out of a peak or promontory since the ice passed over it and the view that the ice never advanced so far. Melville Monument, a somewhat similar rocky column rising out of the bay off the face of the ice border a degree farther north, presents a similar alternative, as do also some of the rather rugged islands along the coast, though the majority of these are fluent in contour, and carry implications of precisely the opposite kind.

Beginning just beyond the Devil's Thumb, at about latitude 74° 30′, the coast of Melville Bay, for about 150 miles, is formed much more largely of ice than of land. A survey has recently been made by Mr. Astrup, of Lieutenant Peary's party, which will, when published, add greatly to the existing knowledge of this remarkable coast, which is laid down on our charts with confessed inaccuracy. Not to anticipate this, it may be safely affirmed, on the basis of passing observation, under the favorable conditions of our voyage, that while the coast is not the uninterrupted ice-wall that sailors sometimes represent it (due, perhaps, to the deceptiveness of its frequent and phenomenal mirages) its most dominant and interesting feature is the edge of the great ice-field broken into vertical sea cliffs as it pushes out into the margin of the bay. These cliffs, though very extended, are not wholly continuous. They are occasionally interrupted, not only by promontories standing forth from the base of the ice slope like dormer windows at the eaves of a roof, but also by lower areas whose freedom from ice is less obviously due to altitude. These interruptions, however, are usually limited in

extent. The promontories are closely girt about by ice on their sides and in the rear, and lack only enclosure on the sea face to reduce them to typical nunataks. Indeed, many of the prominences that lie a little back from the coast are thus completely surrounded, and present excellent types of islands in the ice, the Greenlander's nunataks.

From a vessel sailing some distance off the shore (and the broad foot of stationary bay ice rarely gives a ship any other privilege), a considerable tract of the upper slope of the glacier is visible. The sky line lies some miles inland. Only a few of the promontories on the coast rise high enough to be projected across this sky line and interrupt the otherwise continuous stretch of the glacial horizon. The ice does not meet the sky in a simple straight line. It undulates gently, indicating some notable departure of the upper surface of the ice tract from a plane. As the ice-field slopes down from the interior to the border of the bay, it takes on a still more pronounced undulatory surface. It is not unlike some of our gracefully rolling prairies as they descend from uplands to valleys, when near their middle-life development. The convexities are much broken by crevasses. It is not a few gaping fissures here and there, or even at regular intervals, but an intimate cracking open of the whole convex surface, so as to alter its entire expression. As a result, the light reflected from the crevassed portions is brighter than that from the smoother parts, and the undulations are thus set forth delicately but very expressively by the varying tones of the nearly white light. The intimacy and extent of the crevassing on the swelling surfaces is quite remarkable when the relative slightness of their convexities, the breadth and freedom of the sheet, and the evident slowness of motion are considered. The slowness of motion is safely inferred from the limited amount of surface wastage during the short season, and the very moderate iceberg product in proportion to the vast frontage. The undulations are undoubtedly due to the inequalities of the rock surface below. The first impression is that the ice sheet is quite thin and altogether subservient to the basal irregularities. And this is doubt-

less measurably true. But it appears also to be an expression of brittleness rather than of viscidity, as a property of the ice. Its competency to stretch must be very slight. The degree of undulation also shows a feebleness of adaptive fluency.

The surface of the ice seemed to be wholly free from rocky débris save where contact with promontories or nunataks give rise to trivial moraines. Except for these the bay ice seemed no more free of débris than the surface of the glacier. The descent from the sky line to the sea wall must be some 3000 feet, and yet it would appear that no material is brought from the base to the summit. The exposed portions of the icebergs of the region are usually quite free from débris. In a few instances interbedded earthy layers were observed.

A considerable number of icebergs were scattered along the front of the sea wall, held fast within the sheet of bay ice that still remained stationary. In the moving portion of the ice pack comparatively few were seen. It is obvious that the icebergs enclosed within the stationary ice embraced all those that had been discharged since its freezing, which was at most not more recent than the previous fall; indeed, they probably embraced not a few that had been discharged much previous to that, for many of them appeared to be aground, and to have been subjected to considerable wastage since they had been discharged. Large numbers of icebergs were aground on the shallows near Cape York and along the face of the Crimson Cliffs. Captain Nares expresses the opinion that these bergs originated in Melville Bay and were carried westward by the tide, which, coming from the south, is turned to the west by the concave contour of the bay. If this be true, perhaps it should increase somewhat our estimate of the discharge from the Melville ice wall, but the fact that they are aground and wasted, extends the time through which their discharge is to be distributed.

Peaked Hill, a conspicuous landmark on the north side of Melville Bay, introduces another transition of the coast phenomena, a reaction in some measure toward the conditions that prevail south of the Thumb. Peaked Hill is a cone set upon an

irregular ridge, with black, rather ragged outliers in the vicinity. The whole combination has a very volcanic aspect, but there is little or nothing in this upon which to base an inference respecting its nature. Westward from Peaked Hill there are frequent protrusions of hill and mountain crests and ragged outliers, arranged in an irregular scattered way, but sufficiently thick to give the sea frontage quite as much the expression of a range of mountains with attendant glaciation, as of predominant glaciation interrupted by mountainous projections. The inland ice may be seen sufficiently through the gaps to show that it dominates the country immediately in the rear, and that the mountainous aspect is purely frontal. Frequent ice tongues come winding down between the hills to the sea, and to some extent glacial sheets wrap them about, while local glaciers and snow blankets cover portions of their slopes. The total expression is much more glacial than that of the land border south of the Melville ice wall.

Into the bay east of Cape York very considerable glacial tongues descend from the east, north and west. They push well out into the bay, which probably signifies that it is shallow. During the past season the ice did not move out of the bay (at least it had not at the time of our return, when the season of new ice was at hand) and hence all the icebergs recently discharged remained embedded in the stationary ice. Mr. Astrup informs me that the ice does not usually move out annually but remains for a period of years, and, partly by deeper freezing and partly by snow accumulations, acquires considerable thickness. When it is finally forced out it forms at least a variety, if not the typical variety, of "palæocrystic" floes. Mr. Astrup thinks that glaciers sometimes force such floes out.

Cape York is a promontory of ancient crystalline rock, standing at the junction of Melville Bay with the northern extremity of Baffin's Bay, where it narrows rapidly into Smith's Sound. From this point west-northwestward for some forty miles, the Crimson Cliffs present an abrupt plateau face, down the ravines of which creep a dozen small glaciers. The name "Crimson Cliffs"

is variously attributed to the reddish lichens that grow upon the face of the rocks, and to the "red snow" (*Protococcus nivalis*) which in the latter part of the season gives a very notable pinkish tinge to the remnant snow banks and the granular surfaces of the glaciers. The glaciers take their origin in an undulatory nevé surmounting the cliffs. This appears to be continuous with the great snow cap of the interior, but from its apparent thinness and strong undulation in evident conformity to the rock surface, it seems probable that it is, in effect, a local ice cap. It is probable that the Cape York glaciers on the one hand and the noble

FIG. 15.—Distant view of the Crimson Cliffs, showing ice cap, glaciers, icebergs and ice floes.

Petowick glacier on the other, draw away and discharge the surplusage of the adjacent portion of the main ice cap, so that it does not push forward over the edge of the Crimson Cliffs. At any rate, the glaciers that creep down the face of the Crimson Cliffs are all small and give no hint of relationship to anything beyond the limited though rather considerable snow fields on the summits immediately above them. These little glaciers descend steeply, winding through their narrow valleys in full conformity to topographic demands. The most of them do not fully reach the sea level, but terminate at varying heights above it. A few actually protrude into the water, and have vertical frontal cliffs. Terminal and occasional medial moraines are present. There appears here an interesting phenomenon which was frequently

noted farther northward — the construction of a causeway by the glacier through the accumulation of its own débris beneath it. In their upper parts the glaciers appear to fit snugly in their respective valleys, and they doubtless have carried along with themselves all débris that may have been loosened beneath them; but on reaching the lower gradients near the sea level much of this has been deposited, so that they are now creeping out on embankments of their own construction. It is perhaps not necessary to

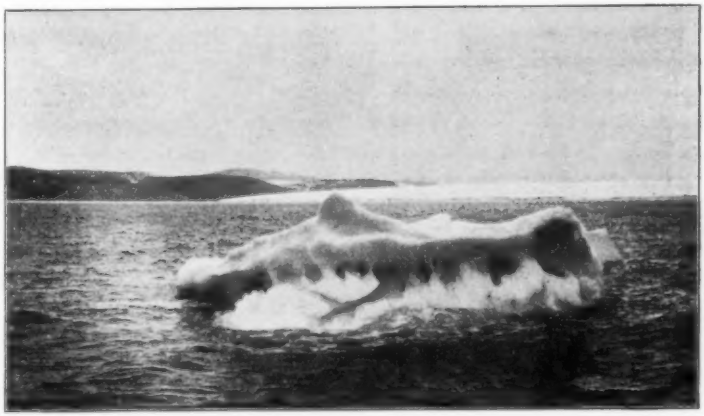


FIG. 16.—Distant view of a part of Petowik glacier. Ice mass in foreground showing cavernous melting at former water-line with subsequent tilting.

suppose that they have built these up actually beneath themselves, as they may have constructed them by successive terminal deposits. When shorter than they now are they may have thrown down their material at their front edges, and subsequently have advanced upon it, building out the terminal accumulation in front as they slowly advanced. Whatever be the explanation (and passing observation gave no data for determining the mode of construction), the interesting fact remains that the glaciers become subservient to their own accumulations, instead of forcing them bodily out of their way.

Near the western extremity of the Crimson Cliffs there stands,

two or three miles off shore, a very notable island, known as Conical Rock. Its name indicates its form, but does not suggest the jaggedness of its surface, which is quite pronounced, and again raises the question whether the great ice sheet has ever passed much beyond its present limits.

A short distance beyond this, the Petowik glacier, the noblest of the isolated glaciers of this portion of the coast, presents itself. It has a breadth of seven miles, and arches forth gently into the bay. Its profile is singularly regular and rises gently as it stretches back from the edge of the sea cliff into the interior, where the glacier merges into the plains of the inland ice. Its transverse profile is a gentle arch with but slight convexity in the central part. The upper surface is comparatively free from crevasses, and nowhere in its course, so far as seen, did it show any cataracts. Its general expression is similar to that of the great Frederickshaab glacier of South Greenland, though it is much inferior to it in dimensions and impressiveness. The Petowik glacier appears to be relatively inert, discharging but few icebergs.

Between the Petowik glacier and Wolstenholme Sound, the coast is relatively free from snow and ice. In the depths of the Sound large glaciers descend to the sea level or to its vicinity, but only very distant and imperfect views of these were had. Dalrymple Island, in the mouth of the Sound, closely resembles Conical Rock in its form and surface ruggedness, and doubtless has the same significance. A photographic illustration of it has been given in the introductory narrative (Fig. 3). Saunders Island, which stands farther within the mouth of the Sound, introduces us again to stratified clastic rocks. These have been absent since we left the Disco region. From this point they stretch to Cape Alexander, at least, though they are not everywhere the border rock. So far as identified, they consist of sandstones and shales.

Along the shores of Granville Bay, and northward to Cape Parry, at the mouth of Inglefield Gulf, there are several glaciers of medium dimensions which descend from the ice cap of the plateau immediately above them, which is an extension of the

inland ice. These glaciers, however, occupy only a small fraction of the coast, the greater portion of which is ice-free land. It differs from that of South Greenland in the important fact that it is a plateau border and not mountainous. The clastic rocks are rounded into soft contours, whether by long exposure to meteoric agencies or to glacial action is not evident at a distance, and need not be considered here, as this brings us to the entrance to Inglefield Gulf, where a closer examination will be possible.

This running sketch of passing observations has brought into imperfect view the various coastal types of West Greenland; rugged serrate mountains; rounded sub-mountainous tracts; coast-island fringes; ice-fields ending in sea cliffs; ice-fields struggling with mountainous protrusions; rock-walls capped with nevé and traversed by "hanging" glaciers; and plateaus of softened outline, surmounted by ice-fields whose tongues creep down wide and less steep valleys.

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STUDIES FOR STUDENTS.

AGENCIES WHICH TRANSPORT MATERIALS ON THE EARTH'S SURFACE.[1]

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When account is taken of all the foregoing considerations touching the character of the drift, the character of the rock surface which underlies it, and the relation of these to each other, we are able to exclude as principal agents of the drift, many of those forces which transport materials on the earth's surface. The agencies prominently concerned in shifting loose materials are wind, water and ice. Other agencies of extreme violence, such as earthquakings and volcanic explosions, occasionally affect small areas. Suddenly and locally they accomplish very considerable results in the way of shifting material from one point to another. The direct action of gravity, too, by producing landslides and by carrying loosened masses of rock down steep slopes effects much in the way of transfer of surface materials. But we have no warrant for believing that any or all these agencies can move such materials as those of the drift

[1] The sequel to the articles which appeared under the heading *Studies for Students*, Vol. II. Nos. 7 and 8.

through any such distances as the drift has been carried. On the contrary, we have the best of reasons for believing that they could not.

Wind.

The strongest winds are able to carry no more than very small pebbles along with the sand and dust which make up their chief load. Transportation of the drift by the wind is therefore impossible. Locally the wind has moved the sand of the drift, heaping it into dunes or spreading it with more uniformity over surfaces which it did originally occupy. But although the wind may have played a part in the deposition of the great body of material included under the term drift, either at the time of its origin or since, it can have been no more than a very subordinate factor. The work of the wind, so far as the great body of drift is concerned, can be looked upon as nothing more than incidental. There remain to be seriously considered, therefore, only two agencies, ice and water.

Water.

Next to the wind, moving water is by far the most widely active agent which is now shifting material on the earth's surface. The countless streams, large and small, the waves and currents of the thousands of lakes, as well as those of the seas, are constantly moving those materials which come within their reach, and do not exceed their power. Streams, waves and currents, do each their appropriate work. The results have much in common, yet each has its diagnostic marks.

Streams. Streams sometimes carry heavy burdens of earthy material. If the velocity of a stream be great, and particularly if its gradient be high, it is able to roll along stones of considerable size. The torrents which course down hillsides after violent showers sometimes carry blocks of stone weighing hundreds of pounds. If the high velocity of the transporting stream were to be constantly maintained, great quantities of coarse material might thus be carried down in the long process of time. The presence of coarse material, even bowlders of some size, is

therefore no proof that the deposit containing them was not made by a stream.

The transportation of coarse materials by streams may be facilitated by the co-operation of ice. When the rigors of winter are past, and the snows upon the hills and mountains are being rapidly melted, the swollen streams break up the ice which has imprisoned them, and hurry the broken masses forward with their increasing floods. As these masses of ice are torn away from the banks of the streams, they sometimes carry with them very considerable quantities of earth, sand, gravel and even bowlders, to which the ice had frozen. These materials are deposited at some point further down the stream, or in the lake or sea to which the river flows.

But however we may conceive the work of rivers to be abetted, the material which they transport could never be deposited on land surfaces outside the limits of their valleys. It might be distributed widely by the waves and currents of the seas and lakes into which the rivers carried it, but it could never be deposited on the tops of hills or mountains. Furthermore, the deposits made by streams, except in the case of alluvial cones, have surfaces which are nearly plane. They are never marked by such hills and depressions as often characterize the drift. The difference is not one of degree, but one of kind. However vigorously we may suppose streams to have acted, therefore, and however we may suppose their proper work to have been modified by co-operating agencies, they fail to account for the distribution of the drift or for its topography; and not only do they fail to account for the distribution and topography of the drift, but its distribution and topography are such as to constitute positive and conclusive evidence against the reference of the larger part of the drift to rivers acting under any circumstances whatever. Since the distribution of the drift disproves all hypotheses which ascribe it to rivers, the argument need not be pursued further. But if we were to examine in detail each of the characteristics of the drift with reference to its production by streams, we should find that their combined testimony is

not only negatively but positively overwhelming against the notion that the bulk of the drift can be accounted for by any phase of river work of any degree of intensity assisted by any other agent in a subordinate capacity. Streams, then, were not the principal agencies concerned in the deposition of the drift, though nothing here said is to be construed to mean that they did not play a subordinate part. The fact that stratified drift frequently extends much further south in valleys than on the adjacent uplands suggests that rivers may have played a subordinate rôle in the transportation and deposition of the drift.

Materials deposited by streams along their valleys are properly called "river drift." Generally speaking, river drift is so unlike the general sheet of drift under consideration, both in its inherent character and in its relations, that the one is not likely to be mistaken for the other. Yet the range of variation, both in the drift and in river drift, is great. When the variations are toward a common limit, as is sometimes the case, the one may closely simulate the other. But this does not appear to be true of any considerable body of the two types of drift, extending over any considerable area. Torrential deposits, such as are formed at the bases of steep mountain slopes, or along the valleys of streams which have high gradients, may closely resemble the drift so far as their physical constitution is concerned. But the distribution of such deposits, the shapes of their constituent stones, and their freedom from striation and planation, are generally sufficient to betray their origin. Lithologically, too, torrential deposits contain only materials which might have been gathered from the drainage basin of the stream concerned, while the constituents of the drift are rarely so limited in their range. If the materials entering into the constitution of torrential deposits were derived from the drift, and not greatly modified in the process of reworking, the resemblance of these deposits to the drift, and especially to the stratified drift, might be very close. Even in this case their distribution and structure might be decisive. Furthermore, if the existence of the drift must be presupposed in order to account for torrential deposits

which might be mistaken for the drift, it is clear that we have in the torrents no explanation of the drift itself.

Lakes and seas. By their waves and currents lakes and seas effect extensive transportation. Along the bases of steep cliffs storm waves sometimes have sufficient strength to move loose masses of rock many tons in weight. But bowlders so large as those common to the drift cannot be moved by the water of lakes or seas except along shores where waves are violent. Even along shores subject to strong waves, great bowlders cannot suffer extensive transportation at the hands of waves and currents. Even where the movements of the water are competent to transport them, they are worn out, or at any rate greatly reduced in size, before being carried far. Yet some of the huge bowlders of the drift have journeyed scores and even hundreds of miles, and that over regions where there is not only an absence of evidence that shores existed, but where, on the contrary, there is the best of evidence that shores did not exist during the time of drift formation, and where there is the best of evidence that seas or lakes have not existed since that time. Neither sea nor lakes can be responsible for their present position.

Again, deposits made by seas and lakes are composed of materials which are well assorted and stratified. The larger part of the drift is neither assorted nor stratified. Deposits made by seas and lakes contain relics of the plant and animal life which inhabited them while the deposits were making. The great body of the drift is devoid of lacustrine and marine fossils. In certain restricted localities, however, the drift contains marine fossils and in certain other restricted localities lacustrine fossils. The significance of these exceptions will be noted later. In spite of them the statement remains true that marine and lacustrine fossils are generally absent from the great body of the drift. It is hardly necessary to state that where the drift is made up in part of rock which contains fossils, these fossils reappear in the drift. Such fossils have no significance except in showing what formations contributed to the drift of the localities where the fossils exist.

Deposits made by standing water are necessarily restricted in

their vertical range. They cannot extend above the level reached by the crests of the highest waves, and in great thickness they cannot extend below the depths reached effectively by the bottoms of the waves. Although small amounts of fine sediment may be carried far out into lakes or into the sea, especially along the courses of currents, yet considerable deposits of lacustrine or marine sediments coarser than fine clay must be confined to a narrow belt of shallow water along the shores. Even within this belt there is a systematic gradation of material on the basis of size, the coarser being left nearer the shore, while only the finer reaches the outer part of the zone of abundant deposition.

If the level of the standing water along whose shores deposits are made varies, the shore deposits made at successive stages will have a corresponding vertical range. The deposits making at any given time must have an essentially horizontal upper limit, corresponding approximately with the level of the water. The earth's surface parts are known to be undergoing differential vertical movements, and are known to have suffered such movements in the past. It follows that shore deposits, horizontal in position at the time they were made, may not always remain so. But if they fail to preserve their original horizontal position, they can never assume any new position except such as might be given them by crustal movements.

No lake and no combination of lakes could cover the area which the drift covers. The only body of water which could have been everywhere where the drift is, is the sea. If the sea covered the whole of this area, including its mountains, and if the land gradually rose, or the sea receded, all parts of the drift area would have found themselves, sooner or later, at the level of the sea. In this way only could all parts of the drift-covered area have been affected by those parts of the sea along which, and along which only, abundant deposition of coarse materials can take place, if water alone be concerned.

To account for the absence of drift from the southeastern part of the United States, lower on the whole than the drift-covered territory to the north, it would be necessary to suppose that this

area was high at the same time that the drift area was submerged, if the sea was concerned as a principal agent in the origin of the drift. Such a supposition, if made, would have to be made not only without supporting evidence, but in the face of abundant and positive adverse evidence. If anything further need be said in refutation of the violent hypothesis referred to above, reference might be made to the position and relations of the line which marks the southern terminus of the drift. It will be remembered that this line is far from horizontal. Not only this, but it is a line which could not have been deformed from a horizontal position by post-drift warping. Without inquiring whence the sea could have derived material for such coarse deposits as the drift, in case the whole of the drift-covered territory was submerged, such extensive transportation of coarse material as the drift demonstrates could not have taken place at the hands of water alone.

Thus from the cursory examination of a few of its characteristics it is seen not only that lakes and seas, unaided by other agencies, fail to account for the drift, but that the drift bears in itself and in its relations, positive and conclusive testimony against the suggestion of its genesis at the hands of lakes or sea, acting as principal agents. The nature and the arrangement of the striæ on the rock beneath the drift would alone disprove its origin at the hands of any body of standing water. Were each feature of the drift, and each feature of the underlying rock examined in detail with reference to the possibility of its origin at the hands of standing water as principal agent, the combined testimony of all would be found to be overwhelming against the notion of such an origin.

If seas and lakes were not principal factors in the production of the drift as a whole, it does not follow that they were not subordinate factors, or that locally they were not of great importance.

Water and Ice Co-operating.

Shore-ice or pan-ice co-operating with the water of lakes and seas.—It has already been seen that streams, even when aided by the ice which forms upon their surfaces in winter, cannot account

for the drift. It has been seen that lakes could never have covered the drift-mantled country, and therefore that the drift did not originate wholly or mainly through the agency of lakes. It has also been seen that the sea, acting alone, cannot account for the drift and its accompanying phenomena. It remains to inquire whether standing water, aided by the ice which forms, or which under favorable conditions may have formed on its surface, can account for the phenomena which water alone cannot explain. Since the distribution of the drift proves that it is not of lacustrine origin, and since lake ice is restricted to lakes, it is clear that lake ice cannot afford the key to the explanation of the drift. Yet because the action of the lake ice is more familiar than that of sea ice, it will be profitable to study it briefly.

The ice which forms upon the surface of lakes in winter may be subject to considerable movement both during the winter and in the spring. On fresh water, ice forms at a temperature of 32° Fahr. The ice thickens as the isothermal plane of 32° sinks beneath the surface. Although water expands on becoming ice, the ice cannot suffer reduction of temperature without contraction. If its temperature be lowered greatly, and that suddenly, as often happens in winter, the contraction of the ice is correspondingly great. The ice cover which fits a lake snugly at a temperature of 32° becomes too small, after contraction, to cover the whole surface of the water. It must either draw away from the shores, or crack. If the attachment of the ice to the shore is stronger than the cohesion of adjacent parts of the ice, the ice will crack. Otherwise it will draw away from the shore. Both withdrawal from the shore and cracking might take place in the same lake at the same time. The intense cold of the winter nights in temperate latitudes affords abundant illustration of both results. In whichever way they are formed, the breaches caused by the contraction of the ice will be healed by the freezing of the water which rises in them, and again the cover of ice fits snugly over the water beneath. When the temperature again rises, the ice expands. It was already large enough to cover the water, and expansion makes it too large. It therefore crowds the

shores of the lake and tends to advance upon them. Some part of the strain may be relieved by the arching of the ice, but this could not do away with shoreward pressure. Under favorable conditions, the shoreward movement may be considerable. When the shoreward movement of the ice begins, its margin may be frozen to stones of greater or less size. As it crowds upon the shore, the stones frozen to its lower surface will grind the surface over which it moves. If this surface be of material capable of receiving striæ, as limestone, it may be striated as the bowlder-bearing ice is shoved over it. Taken singly, the striæ thus produced may closely resemble those found in association with the drift. At the same time, the stones which marked the bedrock would themselves be worn after the fashion of the stones of the drift. The process of ice movement here described may be repeated many times in the course of a single season.

At the close of winter, fed by the swollen currents of streams flooded by melting snows, the water in the lakes rises. The melting ice is broken into blocks. In the flooded condition of the lakes, these blocks are carried above and beyond the usual shore lines. Waves may drive them still further. Where the slopes of the shore are gentle, and the waves high, the ice may be driven many feet above the high-water shore line, and many rods beyond it. In this movement, those blocks of ice which were originally frozen to the shore sometimes carry stony materials in their bases, and, thus armed, wear the surface over which they are shoved. The ice is sometimes broken up and driven on shore during the winter as well as in the spring. Once on the shore, the ice blocks may be frozen to the land surface, to be again moved inland by the waves and crowding ice blocks of succeeding storms and floods. While it seems altogether possible that striæ may be produced both on the bedrock and on loose stones by the shoreward movement of lake ice, good examples of striæ demonstrably thus produced, and comparable to those affecting the surface of the rock beneath the drift, are not known. The vertical range of such striæ would be very limited at best, unless the level of the lake changed.

Sea water freezes at a temperature of about 28° Fahr. With respect to temperature, sea water ice is believed to behave like other ice. Although ice never covers the sea from shore to shore, except in narrow bays, fjords, etc., belts of ice of considerable width are formed on its surface in high latitudes. This ice is sometimes broken up during the violent storms of winter, and uniformly suffers this fate in the storms of spring. Thus arise blocks or "pans" of floating ice, some of which are many acres in extent. These blocks of floating ice, frozen together in larger or smaller numbers, constitute the ice-floe of the northern seas. The ice of the sea is subject to all the movements which affect the ice of lakes, and to such additional movements as the tides may bring about. Since the waves of the sea are stronger than the waves of lakes, the ice of the sea may be correspondingly more effective in wearing its shores.

The striæ produced at any given period by pan-ice or ice-floe, must be confined to the shores. As developed at any one period of time, their vertical range must be exceedingly small, and the altitude at which they occur should nearly correspond at all points about the margin of any body of water on the shores of which they are formed. A great vertical range might conceivably be given to shore-ice or pan-ice striæ, if the water level was inconstant in relation to the land. If the land along shore were to rise gradually a thousand feet, or if the sea were to fall an equal amount, it can be conceived that shore-ice might produce striæ throughout the whole vertical range between the first and last water levels, if all conditions were favorable. But even on the most liberal interpretation possible, this conception does not at all meet the case of the striæ which are associated with our drift. Not to speak of other difficulties, the systematic arrangement of these striæ (see Vol. II., p. 849) is altogether fatal to the idea that ice along any shore, or along any combination of shores, was the principal agent concerned in their production.

If it be conceived that the whole area of land covered by drift was beneath the sea during the drift period, every part of the land surface, as it emerged, must at some time have been a sea

margin. Under such circumstances, if it be assumed that the temperature was low enough to freeze the sea water to considerable depths, the shore-ice might have done all that shore-ice can ever do in the way of developing striæ. But even with so violent an assumption, the direction of the striæ would be likely to betray their origin. Striæ formed in this way would be more or less nearly perpendicular to the line of the shore on which they were formed. On the slopes of isolated elevations, as they passed through the insular stage during emergence, the striæ formed by shore-ice should run up and down the slopes on all sides. The same would be true on the slopes of mountain ranges. The striæ would thus be developed in a sort of system, a system determined by the method and position of their formation. The waves, striking the shores at different angles might seriously interfere with the regularity of the development of the system. The striæ associated with the drift are arranged systematically, but the principle underlying their arrangement is radically different from that here stated. Taken as a whole, they do not stand in any definite relationship to any existent body of water, or to any body of water which can be conceived to have existed in the past.

While therefore shore-ice may be conceived to produce striæ simulating those beneath the drift, and while certain violent assumptions, if admitted, might enable us to conceive of a widespread development of these striæ, it is still true that such ice could never have produced any considerable part of the striæ accompanying our drift. Even if this were not true, the drift possesses numerous characteristics which would make its reference to shore-ice impossible, and it fails to possess numerous other characteristics which would certainly belong to it had any phase of shore-ice been the principal agent of its production. For example, if shore-ice were the agent of the drift, the great body of it should be stratified, since it was deposited mainly in water. However effectively the action of shore and floating ice might have destroyed the superficial stratification along successive shore lines, it could not have destroyed it to any considerable depth. Again, the constitution of the drift, and the distance and

direction of its transportation, are altogether conclusive against any such conception of its origin. Shore-ice could not account for the wide transportation of the drift, since shore-ice does little more than shove about, through short distances, such materials as are already at hand. It does not transport them in quantity, widely. The topographic distribution of the drift, too, seems to put insuperable difficulties in the way of the pan-ice theory. It does not follow that standing water and shore-ice have played no part in the production of the drift because they cannot be looked upon as the principal agents concerned.

Icebergs. Icebergs emanate from glaciers. They may float out upon any lake or sea to which glaciers descend, and they may distribute themselves as widely as the conditions of temperature, wind, and water movements allow. They may carry such stony materials as the glaciers from which they originated were possessed of. This they may distribute as widely as they are drifted. We have now to enquire whether icebergs, conjointly with the water of lakes and seas, could produce the drift of the North American and European continents.

Icebergs cannot float beyond the limit of the lakes and seas on which their movements are dependent. The drift which they distribute cannot extend beyond these limits, and may fail by varying amounts, to reach them. These limits are vertical as well as horizontal. Berg drift can cover no lands which were not covered by the seas or lakes into which glaciers calved the bergs. The distribution of the existing drift by icebergs presents essentially the same difficulties, from the topographic standpoint, as its distribution by the sea. From the areal standpoint, the difficulties seem at first less overwhelming, since the southern and western limits of the drift might be thought to correspond with the geographic limits to which icebergs floated. On this hypothesis, the outer limit of the drift should be ill-defined, since very few bergs would reach the limit attained by those which went farthest. The distribution of icebergs today makes this point clear. If the drift were deposited by bergs, it should become thinner and thinner with increasing distance from its

source. If its border were anywhere marked by heavy accumulations, it should be where special topographic relations limited the movement of abundant bergs.

The border of the drift is often ill-defined, but it does not feather out to any such extent as this hypothesis would demand. The border is also frequently well defined, being marked by heavy beds of drift, and this where there is nothing in the topography or topographic relations to occasion local accumulation by means of icebergs.

When specific features of the drift, or other specific phenomena accompanying it, are examined, they are found to afford significant testimony touching the iceberg hypothesis of the drift. If it be inquired whether icebergs could striate the surface on which their drift lies, it may be answered that this could be done to a very limited extent only. An iceberg could not striate bedrock, so long as it was floating. When and where it grounded, it might produce markings upon its bed, but these could hardly be continuous for great distances. Neither would they be straight as a general rule. Bergs are likely to swerve as they ground, and any striæ they might produce would correspond with the direction of this swerving motion. Striæ believed to have been made by icebergs have been seen in a few localities, possessing the characteristics which might have been anticipated.

To be brought into existence by icebergs, the divergent systems of striæ observed beneath the drift would demand an impossible system of atmospheric or aqueous currents. Reference need only be made to the figure (Vol. II., p. 849) showing the arrangement of striæ in eastern Wisconsin. No system of air or water currents could drive the icebergs in such directions as to produce this remarkable system of striæ. Much less could there be systems of air or water currents which would occasion the repetition of the general features of this system many times within the area of drift. Icebergs would also be altogether incompetent to account for the production of striæ in many of the anomalous positions in which they occur, such as the under-

sides of overhanging cliffs, in horizontal grooves in vertical or sloping faces.

Except where icebergs grounded, any deposits they might make would be made through water. They should be largely stratified, although the type of stratification developed by the dropping of coarse and fine material through still water might be recognizably different from that developed in deposits made along shores or by running water. The type of stratification which affects the larger part of the stratified drift, is the stratification developed by rapidly moving streams. It is not the type of stratification which would be developed in material dropped through still water. Further, the relations which subsist between the stratified and the unstratified drift are not such as would exist if the drift were the work of icebergs. Were there no other insuperable difficulties in the way of supposing that icebergs were responsible for the drift, we should find it in the constitution of the drift. It will be remembered that the agents which deposited the drift at any given point, were generally agents which had gathered material all along a somewhat extended course, and that in general the larger part of the material which they left at any given point had been derived from sources close at hand. This is just the work which icebergs cannot do. They can carry such material as they possessed when they set sail, but they can gather nothing along the course of their journey.

Furthermore, if the whole of the drift-covered country were submerged, as must needs be if icebergs alone are to explain the drift, where was the land which nourished the glaciers whence the icebergs came?

From these considerations it seems certain that icebergs were not the sole or the principal agents of the drift. Were all the characteristics of the drift and all the phenomena accompanying it examined in detail, the result of their combined testimony would confirm the conclusions to which this partial examination has led. This would still remain true, even though certain features of the drift might seem to find adequate explanation in the icebergs. Since icebergs were not the sole or the principal agents

concerned in the production of the drift, it does not follow that they may not have played a subordinate part.

Neither winds, nor streams, nor lakes and seas, acting alone, can account for the drift. Neither can their combined activities, attributing to each its maximum, go far toward explaining the remarkable series of phenomena bound up in the drift, or closely associated with it. Even if shore-ice, pan-ice, and icebergs be added, the whole combination falls far short of adequacy, though pan-ice and icebergs might account for some phenomena which water and wind cannot. It is evident therefore that some other agency must have been concerned in the production of the drift, though wind and water and shore-ice and icebergs may have played subordinate rôles.

Glaciers.

A possible agent concerned in the production of the drift is glacier ice. If glacier ice be responsible in whole or in part for the drift which has so great a development in North America and Europe, the study of the results effected by glacier ice to-day should give us confirmatory testimony. It is well known that many existing glaciers increase and diminish sensibly within periods of a few years. Even seasonal fluctuations in size are readily observed. These fluctuations of accessible glaciers facilitate the study of their work, and the careful study of the results which existing glaciers effect, affords a means of testing the possibility of the glacier origin of the drift.

After a glacier has retreated for a distance up the valley which it occupies, an area which was formerly covered by the ice is left bare. The area from which the ice has withdrawn is readily accessible, and the effects of former ice occupancy and activity may be seen. In such situations, the surface is found to be more or less generally covered with a mixture of bowlders, gravel, sand and clay. If many valleys occupied by glaciers be examined, these various constituents of the surface material may be found to co-exist in all proportions. They may be in approximately equal quantities in one valley, or in one part of one

valley, while any one may predominate over all the others elsewhere. In its physical heterogeneity therefore, this stony glacial débris very closely resembles certain common phases of our continental drift. In the glacier deposits of mountain valleys, however, stony material is likely to be more abundant relatively than in our drift.

If the stones of the drift in glacier valleys be examined, a considerable variety of rock types may sometimes be found. The glacier deposits are thus seen to possess lithological, as well as physical, heterogeneity. This is a second point of correspondence between glacier deposits and the drift. If the stones in glacier deposits be studied in connection with the surrounding rock formations which are *in situ*, it is found that the stony material deposited at the foot of any particular glacier corresponds with the types of rock found along the course of the valley through which the ice has come, and further, that pieces of all types of rock represented in the course of the valley through which the ice has come, are liable to be found in the deposits left by the ice on the surface from which it has withdrawn. But in general, the lithological heterogeneity in the deposits of existing glaciers is less extreme than in our drift.

In the glacier deposits, the various constituents, ranging from huge bowlders to fine clay, may often be seen mingled together without trace of stratification, just as in our drift. But stratified deposits are by no means wanting. Beds of assorted sand and gravel may sometimes be seen to overlie unstratified mixtures of bowlders, gravel, and clay in some places, and to underlie similar materials in others. Beds of stratified material may even be inserted between beds of unstratified. In all these characteristics and relations the deposits of the glaciers resemble those of the drift.

Many of the stones of the unstratified glacier deposits possess the subangular forms, and the planed and beveled surfaces which have been noted as characterizing the stones of our drift. The stony material of the stratified drift associated with glaciers is more commonly rounded. Some of the stones left by the glacier,

especially those having subangular forms and beveled faces, are found to be superficially marked with a series of parallel lines, or with multiple series of parallel lines, each series being discordant with each other. These surface markings appear to be identical with those on the stones of our drift. As in our drift, striated stones are less common in the stratified deposits associated with glaciers, than in the unstratified.

Upon careful examination, the fine earth (clay) in which the bowlders are imbedded, is found to consist of nothing more or less than fresh particles of rock, such as might be produced by crushing or grinding the stony matter of the same deposit into fine particles. In this respect also, deposits known to be of glacier origin find close correspondence with the drift. In the glacier deposits, too, the fine material which often serves as a matrix for the imbedded bowlders may sometimes be seen to be foliated, after the fashion of the corresponding material of the drift.

The topography of the deposits made by the glaciers is similar in kind to that which characterizes much of the drift as we know it, but is developed on a less extensive scale. Except in the axes of the glacial valleys the deposits are seen to stop on a descending slope where the ice stops, or where the ice has stopped at some earlier time, leaving the higher part of the valley drift-covered, and the lower part drift-free. Along the axes of the valleys, the deposits of gravel, sand, and silt have a nearly plane surface, and extend beyond (below) the unstratified drift.

The glacier deposits stand in the same relation to the underlying rock that our drift does. Where surfaces of bare rock are exposed to observation they may be seen to be polished and striated, the striæ being parallel with each other, and with the course of the valley down which the ice has moved. Upon the most careful examination, these striations on the rock recently occupied by alpine glaciers are found to be indistinguishable from those on the rock beneath the drift in the drift-covered areas of North America and Europe. If the rock of the valley bottom be laid bare by removing the drift, its surface is seen to be firm and fresh. Any decomposed material which may once have covered it has

been swept away, as well as all that part of the rock which had been affected by the disrupting and decomposing effects of surface exposure. In all these respects, the correspondence between the deposits made by glacier ice and the drift seems complete.

So too, if knobs or bosses of rock, large or small, chance to be discovered by the retreat of the ice, they may be seen to possess the form of *roches moutonnées*, with one side worn more than the others, and that the side facing up the valley. Now and then the striæ affecting the surface of these *roches moutonnées* may be seen to be deflected from their normal course down the valley, and to be bent round the bosses, showing that the elevation influenced the details of the movement which made the striæ, without turning the striating agent out of its general course.

It is sometimes possible to go back a short distance beneath the ice itself. The many caves made by natural and human agencies afford such opportunity. Under the ice one may often be fortunate enough to see the contact of the glacier with its bed. Under favorable circumstances the lower part of the ice may be seen to be set with stones and with other materials of all grades of coarseness and fineness. The movement of the rock-shod ice is too slow to be sensible, but it is easy to see that if it move at all, no matter how slowly, it must powerfully corrade its bed. At the same time that the bed of the glacier is striated and polished, the stones in the bottom of the ice, themselves the graving tools, will suffer wear similar to that which they inflict. Not only this, but if the different parts of the ice move at different rates the stones will rub one another during the movement. As they rub against one another, or as they rub against the bed over which the ice is moving, flat surfaces as well as striations will be developed. If for any reason the stones turn in their ice-setting, as when they encounter a resistant object in the rock-bed, they may expose a new surface to planation and striation, or the old surface may be lined in a new direction, thus developing a second set of striations crossing the first. If any particular stone is turned frequently enough and rubbed hard enough against its neighbors, or against the glacier's bed, successive sets of striæ may be effaced.

Those which finally remain, when the ice has deposited its load, will be only those which were last named, or those which escaped destruction. As successive sets of striæ on drift stones are obliterated, new ones taking their places, the stones become smaller. If the process be continued long enough, a stone may be completely worn out. The product of the wear would be rock-flour. Rock-flour, the product of glacial grinding, is carried on beneath the ice, and constitutes an earthy or clayey matrix, in which the accompanying stones and bowlders are imbedded. It is identical with the "clay" in which the bowlders are seen to be imbedded on the land from which the ice has receded. It is comparable in all respects to the matrix of our bowlder-bearing clays.

If one is fortunate enough to go beneath the ice at the point where a stream issues, it may be seen that the stream, even while its course is beneath the ice, is carrying such material as its velocity enables it to transport, and that it is continually dropping parts of its load. The deposits made by flowing water beneath the ice are stratified, as the deposits of running water always are. Should the ice crowd out over the stream's bed, as is possible, displacing the water in the operation, such parts of the stratified deposits as were not ground up and borne away by the ice might be buried beneath the unstratified deposits which it might make. Since this process of change may be repeated, ice succeeding water, and water ice, at any given point, we discover at least one way in which alternations of stratified and unstratified deposits may be brought about in connection with glacier ice.

The flowing water beneath the ice does not stop with the terminus of the glacier itself, but issues as a swift river, hurrying on down the valley, with such load of sediment as it can carry. These materials are spread out in alluvial plains beyond the edge of the ice, wherever the stream is unable to carry them further. Considerable plains of stratified material have been built up in this way by the ice-born rivers, beyond the ends of many alpine glaciers. In some cases they extend many miles down the valleys, the coarser materials being near the ice and the finer further away. In every essential particular concerning constitu-

tion, structure, form and relationship, these valley plains resemble the many valley deposits of stratified drift, which stretch beyond the unstratified drift in our own country and northern Europe.

All these considerations make it clear that there are many points in common between the deposits made by alpine glaciers, and the drift of the continental areas. Indeed, the correspondences between the two formations are so close, so numerous, and comprehend so many phenomena related to one another in intimate and nicely adjusted ways, that it is difficult to see how they could have been brought into existence by any other than identical agencies.

The physical heterogeneity of glacier deposits considered in relation to the sources whence their materials were derived; the lithological heterogeneity of these deposits likewise considered in relation to the sources whence the materials came; the sizes, shapes, and marking of the coarser parts of these deposits; the physical and chemical condition of their finer parts; the stratified, unstratified, and foliated structures of the various parts of these deposits in their relations to one another and to topography; the relation of these deposits to the rock upon which they rest; the frequent termination of the unstratified parts on declining surfaces; the extension of the stratified parts far down the valleys beyond the unstratified parts; the topographic relations of these deposits and their own topography; the systematically disposed striæ on the rock beneath them, taken in connection with the direction in which materials have been transported; the shapes of the hills worn by glaciers, and the relation of these forms to other associated phenomena; the general surface expression of the region worked over by a glacier, in contrast with adjacent regions which have been so affected; all these phenomena, so peculiar, so distinctive, and particularly all these phenomena in their manifold, and intricate, and peculiar, and nicely adjusted relations, afford a remarkable series of criteria for the recognition of glacier deposits, even in regions which now possess no remnant of ice.

The various marks left by glacier ice on the bed over which

it has moved are so many and so distinctive, and stand in such nicely adjusted relations to one another, that it hardly seems credible that any second agency or combination of agencies could produce results so similar as to be mistaken for them, if all the foregoing characteristics and relations are clearly developed and open to observation. It is not to be understood that all the marks of glacier deposits, or all the phenomena accompanying them, are always present at every point, or within any circumscribed area where glacier ice has been. The study of considerable areas of glacier deposits may sometimes be necessary for the recognition of all the features and relations referred to. Some, or even many of them may altogether fail of development in a given locality. Those which are developed may be but feeble. In a limited area of drift where relations are not discernible, or where many of the various characteristics referred to above are but poorly developed, or where they are not open to observation, glacier deposits might be confused with those produced by certain other agencies, especially if the region in question be one where glacier ice is not known to have been. If a glacier deposit be very ancient, it may have lost, by decay, most of its diagnostic characteristics; or, since its origin, it may have suffered alteration, with the effacement of its distinctively glacial marks, at the hands of some geological agent other than ice. It is not to be understood, therefore, that glacier deposits can always and everywhere be recognized at sight, especially in a region where glaciers do not exist, and where they are not known to have existed. But it is confidently believed that any series of typically developed glacial deposits which have suffered so little change that they still preserve the characteristics which the ice impressed upon them, cannot fail to give evidence of their origin, if their characteristics and relations are open to observation.

If glacier ice alone be responsible for the drift, it is necessary to suppose that the whole of the drift-covered area was overspread by an ice-sheet. Alpine glaciers are so small and so connected with mountains, that studying them alone, it seems

incredible, at first, that any extension of such glaciers could be great enough to account for the drift deposits of so great areas as those of North America and Europe. Fortunately, our knowledge of glaciers and of glacial phenomena is not restricted to Switzerland, or even to the type of glaciers which has been termed alpine. Larger bodies of land ice exist in various parts of the world. The largest of these which has received even a small amount of attention is the ice cap of Greenland. But this is accessible only with difficulty, and has received little attention compared to that which has been bestowed on many mountain glaciers. While, therefore, the Greenland ice-sheet might afford a closer analogy to a continental ice cap than alpine glaciers do, it has not been sufficiently studied to give us so reliable a point of departure in the discussion of the subject, as the smaller glaciers. But it is so large, and departs so far from the alpine type of glacier, as to give us an enlarged idea of the dimensions which glacier ice may attain, and of the results which it may accomplish. Switzerland has an area of about 16,000 square miles. It is said to harbor 471 glaciers, 138 of which are more than four and three-fourths miles long.[1] According to official surveys, the 471 glaciers, and the snowfields associated with them, have a total area of a little more than 700 square miles. The estimated area of the ice cap of Greenland is about 300,000 square miles, an area nearly nineteen times as great as that of all Switzerland, and about 422 times as great as that of the united area of all the Swiss glaciers and snowfields.

The drift of North America is estimated to cover an area of about 4,000,000 square miles,[2] an area only a little more than thirteen times as large as the area of Greenland's ice sheet. Stated in the form of ratios, therefore, the snow and ice-covered area of Switzerland is to the snow and ice-covered area of Greenland as 1 is to 422; while the snow and ice-covered area of Greenland is to the North American area of drift as 1 to 13. The ratio between the entire snow-covered area of Switzerland and the

[1] HEIM, Handbuch der Gletscherkunde, 1885.

[2] UPHAM: Appendix to Wright's "The Ice Age in North America."

area of the ice cap of Greenland is, therefore, much greater than that between the latter and the drift-covered area of our continent. From the standpoint of ratios, it is an enormously greater jump from an alpine glacier to the ice cap of Greenland, than from the ice cap of Greenland to such an ice sheet as must have covered the northeastern part of our continent, if the drift be the product of glacier ice. If the comparison of the three areas be made without resort to ratios, their relative sizes are expressed approximately by the following numbers: 1, 422 and 5634.

But even Greenland does not possess the greatest ice sheet known. The Antarctic continent — for this land and ice mass seems to merit the name of continent — is almost completely covered with ice, so far as known. While its area has not been determined with accuracy, it has been recently estimated to contain at least 4,000,000 square miles,[1] that is, an area equal to the great sheet of drift of North America, an area twice as great as that of the drift which mantles northwestern Europe. The existence of so great an ice sheet today makes it easier to think of the existence of an equally extensive ice sheet elsewhere in the past. It removes the element of incredibility which, at first thought, seems to attach to so striking a theory as that of the glacial origin of the drift. From the standpoint of knowledge concerning ice sheets, the glacier theory is a possible theory, but it is not to be understood that the existence of an Antarctic ice sheet, equal in size to the area of North American drift, is any argument for the glacier origin of our drift. It is more difficult to account for the existence of an ice sheet in temperate than in frigid zones. But in spite of the difficulty, our study of the drift has led us to the conclusion that glacier ice was the principal agent concerned in its production.

Glaciers and Icebergs Co-operating.

Granting that glacier ice was the principal agent of the drift, may it not still be true that other agents were concerned in its production? If so, to what extent? It is well known that the

[1] Murray. Proceedings of the Royal Geographic Society. 1894.

earth's surface is subject to movement. Considerable areas are known to undergo slow elevation, while other adjacent or distant areas are suffering subsidence. If, during the drift period, glaciers formed somewhat extensively on the higher lands now covered by the drift, it might be conceived that a moderate subsidence would allow ice to float out from the glaciers of the higher lands over the waters covering the intervening lower areas, thus distributing the drift over them. That is, the drift might be thought to be the joint product of glaciers and icebergs, glaciers working on the higher lands and icebergs over the lower. Conjecturally, the relative importance of these two agents might vary greatly, but the glaciers must have remained sufficiently extensive to give rise to the ice of the icebergs. But unless it attributed the chief work to glaciers, such a combination hypothesis as this seems open to fatal objections. We have already seen what icebergs can do, and that some of their results may simulate those of glacier ice.

On the hypothesis that icebergs were an important agent in the production of the drift of the lower lands, it would be expected that the distinctively glacial marks would be absent from the lower drift-covered lands, especially near the outer borders of the drift. But this is not the fact. Marks of one sort or another which seem to be distinctively glacial, occur down to the level of the sea, near the southern border of the drift. Among such markings, the striæ on the trap rock south of Jersey City may be mentioned. At various other points too, as in Southern Illinois, at or very near the extreme margin of the drift, striæ are found beneath deposits which appear to be strictly glacial. While admitting that berg deposits may locally closely simulate those of glaciers, we cannot admit that icebergs can produce such striæ as are found near the margin of the drift at many points, even at altitudes scarcely above the level of the sea.

On the hypothesis which we are here considering, too, it would be expected that the position of the southern border of the drift was determined by icebergs, not by glacier ice. We have already seen that both the topographic relations of its terminus, as well

as its inherent character, preclude this belief. From the quantitative standpoint also, the drift border is not always such as would have been produced by icebergs. The drift is often too thick along its border and that in situations where there could have been no shore, and therefore no exceptional accumulation of berg deposits to refer it to icebergs. Like other parts of the drift, the border is made up of materials which were largely gathered close at hand. The glacier ice itself, or some agent capable of accomplishing results which have not been distinguished from those of glacier ice, reached the approximate, and often the exact southern border of the drift-covered area. Further, the character of the drift and its accompanying phenomena indicate that the same forces which were operative on the higher lands in the production of the drift, were operative on the lower also. There is not a higher body of drift of one sort, and a lower body of drift of another sort, as this hypothesis would demand.

Nevertheless, nothing which is here said precludes the idea that lakes of lesser or greater magnitude may have been associated with the ice sheet for longer or shorter periods of time at one stage and another of its development. If such lakes existed, iceberg deposits were doubtless made in them. Berg deposits were doubtless likewise made wherever the glacier ice reached the sea, and since the coastal regions may have been lower than now, it is altogether possible that some of these berg deposits were made on areas which are now land. The foregoing considerations seem only to preclude the attribution of any large part of the drift to bergs, or to floating and grounding ice.

Glaciers and pan-ice.—Any conditions which would allow of the co-operation of glaciers and icebergs, would also allow of the co-operation of pan-ice. If the coastal regions were lower than now, while ice covered that part of the drift area which was not submerged, shore ice might have been operative over a narrow belt determined by the position of the shore line. Since the shore lines must have varied with varying altitudes of the land, ice-floe and other forms of shore-ice may have operated at

one time and another over all that part of the land surface which was submerged during the drift period. If the amount of submergence during the drift period could be determined, we should have the maximum measure of the extent of the operation of pan-ice. Pan-ice might produce results closely simulating certain results produced by glacier ice. On the glacier-pan-ice combination hypothesis, too, it is possible that any region affected by pan-ice at one time may have been affected by glacier ice at an earlier time, and that the effects of the glacier ice were not wholly obliterated by the pan-ice. On the other hand it is conceivable that a zone affected by pan-ice at one time was subsequently elevated and covered by glacier ice which may have partly or even wholly obliterated the effects which the pan-ice had produced.

The results which shore and pan-ice acting alone can effect, have already been studied. That both were operative about the shores of the land which the glacier ice covered during the drift period cannot be doubted, any more than can the existence of icebergs. The question of the relative importance of pan-ice and glacier ice in the production of the drift is a question concerning which there is much difference of opinion.

Except along the coast lines and along the shores of lakes pan-ice could not have been operative. Away from the coasts, therefore, little can be ascribed to it. This removes the larger part of the drift area of the United States from the zone where shore or floating ice in any form can have been long effective. Along the southern part of the drift-covered coast of the United States there is no conclusive evidence of subsidence during the drift period. Further north, subsidence seems to have been a fact, and shore ice was doubtless a more considerable factor. It is not without significance that the Canadian geologists attribute much more importance to pan-ice than do the geologists of the United States. Some of them ascribe to it a work comparable in importance to that which the glacier ice effected.[1] But the difference in views is perhaps one of degree rather than of

[1] Sir J. William Dawson. The Canadian Ice Age. 1893.

kind. The glacial theory involves the co-operation of pan-ice as well as icebergs, or at least recognizes the possibility of this co-operation. At the close of the drift period the relative importance of the results of pan-ice must have depended partly on the vertical range of its activity as determined by changes of relative level of sea and land, and partly on whether the glacier ice subsequently over-rode the zone of the early activity by the pan-ice. The known facts concerning the relative changes of level of sea and land, and the known facts concerning the nature of the drift itself, seem to ascribe by far the larger part of the work involved in its production, to glacier ice. The functions of other forms of ice seem to have been very subordinate.

Significance of the abundance of stratified drift. The fact that so much of the drift is stratified has sometimes been thought to be a difficulty in the way of the glacial theory. It is certainly true that the deposits made by glaciers directly are unstratified; it is certainly true that a very considerable portion of the drift is stratified. But it is to be remembered that the ice of every extinct glacier, be the same large or small, was converted into water upon its dissolution. It is to be remembered that as the ice of any glacier moved forward during the period of its growth, it was constantly melting, so that, barring the loss by evaporation, all the ice of any glacier, from its inception throughout the whole period of its history to final dissolution, was converted into water, and that most of this water ran for longer or shorter courses over the surface of land, either beneath or beyond the ice, often modifying the surface of the drift already deposited by the ice, and often depositing upon it, in bedded form, such gravels, sands, and silt, as fell to its lot to carry and deposit. If northern North America and Europe were covered by huge ice caps, as the glacial theory of the drift supposes, every pound of these stupendous ice masses which did not evaporate was sooner or later converted into water. According to the glacial theory, therefore, the amount of water which was operative jointly with the ice in producing the drift, must have been nearly as great as that of the ice itself. It follows that the glacier theory of the drift not

only allows, but even demands, that a large part of the drift be stratified. It demands that the water issuing from the ice should carry beyond it such products of the glacial grinding as its currents were able to handle. This is exactly what is taking place in glaciers today, and the stratified valley drift extending beyond the great body of unstratified, argues that this is what took place when our drift was deposited.

In searching for the explanation of the drift, therefore, if the facts concerning the drift and its relations are before us in their fullness, it would seem that there is little room for doubtful theorizing. Geologists are now very generally agreed that glacier ice, supplemented by those other agencies which glacier ice calls into being, is the only geological agent which could have produced it. But it is here repeated that this does not preclude the belief that at various times and places, in the course of the ice period, icebergs may have been formed, or that locally and temporarily they played an important rôle. It does not preclude the idea that wherever icebergs existed, berg deposits may have been made. It does not preclude the idea that pan-ice may have been an important factor locally. It does not preclude the idea that, contemporaneously with the production of the great body of the drift by glacier ice, the sea may have been at work on some parts of the present land area, modifying the deposits made by ice and ice drainage. Indeed, there is abundant evidence that such was the fact. There is abundant evidence that in some regions now covered by drift, the land stood lower than now, or the sea higher, when the drift was deposited, or since.

The glacial theory does not deny that rivers produced by melting ice were an important factor in transporting and depositing drift, both within and without the ice-covered territory. It does not deny that lakes, formed in one way and another through the influence of the ice, were locally important in determining the character of the drift. Not only does the glacier theory deny none of these things, but it distinctly affirms that rivers, lakes, bergs, and pan-ice must have co-operated with the glacier ice, each in its appropriate way and measure. ROLLIN D. SALISBURY.

Editorial.

The winter meeting of the Geological Society of America held at Baltimore December 27, 28 and 29 was largely attended, and marked interest was manifested in the papers presented. The foremost thought of all on assembling was the irreparable loss the Society had sustained in the death of Professor G. H. Williams, to whose interest and influence the holding of the session at Baltimore at this time was chiefly due; and the first act of the Society, after the usual opening addresses and preliminary business, was to pay a fitting tribute to his memory. A very graceful and appreciative sketch of his life and labors was presented by Professor William B. Clark, to which several members of the Society who had been most intimately associated with Professor Williams added earnest and sympathetic expressions of their esteem and admiration. An appropriate memorial to Amos Bowman was presented by his colleague of the Canadian Survey, Mr. H. M. Ami.

The program embraced forty-eight titles. With a very few exceptions—and these in part due to illness—the authors of the papers were present and the papers actually read and discussed. The habit of sending in titles of papers yet unborn, and of appearing by name but not in person, has fortunately found little expression at the winter meetings of the Society, and at this session was reduced to a minimum.

The distribution of subjects is worthy of study as indicating the drift of interest and activity. About 18 per cent. of the papers may be classed as predominantly structural. It was notable, however, that in a large number of these, the structural features were but an obvious groundwork for dynamical inferences. Very few were simply descriptive in purpose, though the authors rarely pressed conclusions, preferring apparently to leave

the inferences to enforce themselves. Of purely dynamical papers there were scarcely 5 per cent. though the dynamical factor was obviously a vital element in a large percentage of the other papers. Of papers treating of regional geology there were about 6 per cent. and of formational geology about 15 per cent. The petrological group was *facile princeps*, leading all other classes by a wide margin, and constituting nearly one-fourth of the whole. Glacial titles embraced one-sixth of the whole; the palæontologic and the physiographic, one-twenty-fourth each; while chronology and nomenclature were represented by one paper each.

The over-crowded state of the program was happily relieved by the formation of a temporary subsection of petrology before which the technical petrographic papers were read, while those that embraced structural and dynamical phases of general interest were presented to the whole society. This is a precedent which will doubtless be followed to advantage in the future.

The following is a list of the papers presented:

On certain Features in the Jointing and Veining of the Lower Silurian Limestones near Cumberland Gap, Tenn. *N. S. Shaler.*

The Appalachian Type of Folding in the White Mountain Range of Inyo Co., Cal. *C. D. Walcott.*

New Structural Features in the Appalachians. *Arthur Keith.*

The Faults of Chazy Township, Clinton Co., N. Y. *H. P. Cushing.*

The Formation of Lake Basins by Wind. *G. K. Gilbert.*

The Tepee Buttes. *G. K. Gilbert* and *F. P. Gulliver.*

Remarks on the Geology of Arizona and Sonora. *W J McGee.*

Geology of the Highwood Mountains, Montana. *Walter H. Weed* and *Louis V. Pirsson.*

Genesis and Structure of the Ozark uplift. *Charles R. Keyes.*

The Geographical Evolution of Cuba. *J. W. Spencer.*

Recent Glacial Studies in Greenland (Presidential address). *T. C. Chamberlin.*

Observations on the Glacial Phenomena of Newfoundland, Labrador and Southern Greenland. *G. Frederick Wright.*

Highland Level Gravels in northern New England. *C. H. Hitchcock.*

Variations of Glaciers. *Harry Fielding Reid.*

Discrimination of Glacial Accumulation and Invasion. *Warren Upham.*

Climatic Conditions shown by North American Interglacial deposits. *Warren Upham.*

Glacial Lakes of Western New York. *H. L. Fairchild.*
Lake Newberry, the Successor of Lake Warren. *H. L. Fairchild.*
Notes on the Glaciation of Newfoundland. *T. C. Chamberlin.*
The Pre-Cambrian Floor in the Northwestern States. *C. W. Hall.*
A further Contribution to our Knowledge of the Laurentian. *Frank D. Adams.*
The Crystalline Limestones, Ophiolites and associated Schists of the Eastern Adirondacks. *J. F. Kemp.*
Lower Cambrian Rocks in Eastern California. *Chas. D. Walcott.*
Devonian Fossils in Carboniferous Strata. *H. S. Williams.*
The Pottsville Series along New River, West Virginia. *David White.*
The Cretaceous Deposits of the northern half of the Atlantic Coastal Plain. *William B. Clark.*
Stratigraphic Measurement of Cretaceous Time. *G. K. Gilbert.*
Notes on the Cretaceous of Western Texas and Coahuila, Mexico. *E. T. Dumble.*
The Marginal Development of the Miocene in eastern New Jersey. *William B. Clark.*
Sedimentary Geology of the Baltimore Region. *N. H. Darton.*
The Surface Formations of southern New Jersey. *Rollin D. Salisbury.*
On New Forms of Marine Algæ from the Trenton Limestone, with Observations on Buthograptus Laxus, Hall. *R. P. Whitfield.*
Spherulitic Volcanics at North Haven, Maine. *W. S. Bayley.*
The Peripheral Phases of the Great Gabbro Mass of northeastern Minnesota. *W. S. Bayley.*
The Contact Phenomena at Pigeon Point, Minnesota. *W. S. Bayley.*
The Relation of Grain to Distance from Margin in Certain Rocks. *Alfred C. Lane.*
Crystallized Slags from Copper-Smelting. *Alfred C. Lane.*
On the Honeycombed Limestones in the Bottom of Lake Huron. *Robert Bell.*
On the Nomenclature of the Fine-Grained Siliceous Rocks. *Leon S. Griswold.*
On Some Dykes Containing "Huronite." *Alfred E. Barlow.*
The Characteristic Features of the California Gold Quartz Veins. *Waldemar Lindgren.*
On the Quartz-keratophyre and its associated Rocks of the Baraboo Bluffs, Wisconsin. *Samuel Weidman.*
The Granites of Pike's Peak, Colorado. *Edward B. Mathews.*
The Crystalline Limestones and associated Rocks of the northwest Adirondack Region. *C. H. Smyth, Jr.*
On the Decomposition of the Granitic Rocks of the District of Columbia. *George P. Merrill.*
The Geological Relations of the Tennessee Phosphates. *C. Willard Hayes*
Ancient Physiography as Represented in Sediments. *Bailey Willis.*
A New Intrusive Rock near Syracuse, New York. *N. H. Darton* and *J. F. Kemp.*

PUBLICATIONS.

Report on the Geology of the Coastal Plain of Alabama, Geological Survey of Alabama (pp. xxiv–759). By EUGENE ALLEN SMITH, State Geologist, Montgomery, Ala., 1894.

This report, which treats of all the post-Palæozoic formations of Alabama, is one of value. It deals with matters which are of importance in themselves, and it deals with them in an intelligent way. The matter is so presented that those who are interested in the conclusions only, can find them without laboring through the details, while those whose interests lie in such directions as to make details valuable, will not be disappointed. It is interesting to note that Dr. Smith has conformed to the recent practice of some other state geologists in prefacing his report by an introductory chapter which is intended to make the body of the report intelligible to readers who are not geologists. This practice is to be especially commended in state survey reports. Had it been in vogue since the beginning of state survey publications, geological reports would have been much more widely read, and read with much more understanding and interest by the citizens of the states for whom they are or should be intended. It would appear that the coastal plain formations of Alabama have been worked out with so much detail that in the future Alabama is likely to be the starting point for the correlation of many of the coastal plain formations in the gulf region. The formations and their relations are shown in the following table:

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POST-TERTIARY OR QUATERNARY.

Recent.

1. Coast sands and alluvium, upper part of the Biloxi — 10 to 100 ft.
2. First bottoms and other alluvial deposits of the streams.
3. Soils and rainwash.

Pleistocene.

1. Coast deposits, lower part of the Biloxi, coastal — 150 to 200 ft.
2. Mobile Bay formation. (Mon Louis Island), estuarine, undetermined.
3. Second bottom terraces of the rivers, undetermined but over 60 ft.
4. Ozark or Conecuh sands. Sand terraces — undetermined.

1. Third Terraces of the rivers (surface deposits) - - - - 10 to 20 ft.
2. The Lafayette mantle (Orange Sand, Appomattox) - - - - 25 to 200 ft.

TERTIARY.

Miocene.

1. Pascagoula - - - - - - - Thickness undetermined, about 200 ft.
2. Grand Gulf - - - - - - - " " at least 500 ft.

Eocene.

1. St. Stephens, White Limestone (Vicksburg and Jackson) 200 to 350 feet.
2. Claiborne - - - - - - - - - - - - - - - - 450 "
   - *a.* Claiborne proper - - - - - - - - - - 150
   - *b.* Buhrstone - - - - - - - - - - - - 300
3. Lignitic - - - - - - - - - - - - - - - - - 825 to 850 "
   - *a.* Hatchetigbee - - - - - - - - - - - 175
   - *b.* Bashi or Wood's Bluff - - - - - - - - 80–85
   - *c.* Tuscahoma or Bell's Landing - - - - - - 140
   - *d.* Nanafalia - - - - - - - - - - - - - 200
   - *e.* Naheola or Matthew's Landing - - - 130–150
   - *f.* Sucarnochee or Black Bluff - - - - - - 100
4. Clayton. (Midway) - - - - - - - - - - - - 25 to 200 feet.

CRETACEOUS.

	West Ala.	East Ala.
1. Ripley - - - - - - - - - - - - - - - - - -	250–275	1000
2. Rotten Limestone or Selma Chalk - - - - - - -	1000	000
3. Eutaw - - - - - - - - - - - - - - - - - -	300	300
4. Tuscaloosa - - - - - - - - - - - - - - - -	1000	500

The tracing out of the several formations has made it possible to determine with some accuracy, not only the periods and phases of oscillatory movement of the southern part of the state, but also the deformations which accompanied these movements. Hardly anywhere else along the coastal plain region have we such explicit data concerning Cretaceous and post-Cretaceous movements.

As will appear from the preceding table, a distinction is made between the Recent and the Pleistocene formations, but no sharp line of division is drawn. The coastal portion of the Recent series is found to be continuous below with what is classed as Pleistocene, the two together constituting the Biloxi formation. The division between the Recent and the Pleistocene is therefore in the midst of a conformable series.

The second bottom terraces of the rivers is a fluviatile Pleistocene formation, which at Mobile Bay grades into a deposit of estuarine

origin — the Mobile Bay formation. Traced seaward this formation becomes continuous with the Biloxi, or at least with its lower part. The first, second, and third formations assigned to the Pleistocene in the above table, are therefore the fluviatile, estuarine and marine subdivisions of the same formation.

Five to ten feet above the second bottom terraces, there is another series of sand terraces (No. 4 of above table) along the main streams. From their position these terraces appear to be somewhat older than the second bottom terraces. Along the minor streams, the sand terraces appear to be the main terraces. Sand similar to that of which these terraces are composed covers some of the inter-stream areas and divides, up to altitudes of 100 feet. This is the Ozark or Conecuh sand. This inter-stream sand is compared to the inter-stream phase of the Columbia, as developed at other points on the coastal plain, especially farther north. While therefore the first three of the Pleistocene formations, as shown in the table, are essentially equivalent, the fourth seems to be somewhat older.

Along the principal streams there are "third terraces" which are 50 to 100 feet above the second bottoms. These third terraces consist of red loam with more or less gravel beneath it. Their constitution is in all respects comparable to the constitution of the Lafayette formation, as developed at higher levels. These third terraces sustain the same relation to the Lafayette formation which covers the inter-stream areas, that the sand terraces (No. 4) do to the Ozark or Conecuh sand, though the third terraces and the Lafayette lie at higher levels than the sand terraces and the Ozark and Conecuh sands. The third terraces are very much wider than the second bottom terraces, and are, as all their relations show, considerably older.

The Lafayette formation finds its normal development above the third terraces. Dr. Smith's suggestions concerning the origin of this formation are of interest, and his classification of the same should be especially noted, in view of the fact that he has recently been quoted[1] as holding that the Lafayette is Pleistocene. His words are as follows:

"The general appearance of the formation, and the demonstrably great amount of erosion which it had suffered before the deposition of the undoubted Pleistocene beds, would lead us to conclude that a long period of time and important physical changes occurred between the accumulation of the Lafayette and the Pleistocene deposits. For these reasons, the weight of evidence

[1] UPHAM. Am. Nat. Vol. XXVIII., p. 979, 1894.

appears to be in favor of classifying the Lafayette as the upper member of the Tertiary (Pliocene) formation, and so I have represented it on the geological map of the state" (p. 81–82).

This would seem to be sufficiently explicit, were not some doubt thrown on this correlation in other connections. Thus we find the following:

"The great amount of erosion which took place after the deposition of the Lafayette, and before that of the next overlying deposits, has been urged as an objection to the placing of the Lafayette in the same category with the Pleistocene, but the same objection might, with equal force, be urged against classifying it with the Tertiary, since an equally great, if not greater, amount of erosion occurred between the deposition of the Miocene beds and those of the Lafayette" (p. 82).

This last statement is certainly a little curious. If the alternative were between classifying the Lafayette as Pleistocene or as Miocene, the point here made would have force. But this is not the alternative, and Dr. Smith does not really so regard it, for he classifies the Lafayette, not as Miocene or as Pleistocene, but as Pliocene. If the argument of the last citation had been urged as a reason for separating the Lafayette from both the Pleistocene and the Miocene, making it Pliocene, as Dr. Smith has really done, it would seem weighty. To use this argument for the purpose of raising the question as to whether the Lafayette is not really Pleistocene, is to take the position that an unconformity may be admitted in the Pleistocene, but not in the Tertiary. It is to take the position that different members of the Pleistocene may be much more sharply separated from each other than Pliocene from Miocene. This is a position which we believe to be untenable. The above citation does not seem to the writer to have weight against the classification of the Lafayette as Pliocene, for it is not clear that there may not have been an erosion interval between the Miocene and the Pliocene. It is true that unconformities are known in the extra-glacial Pleistocene, but they are much less considerable than the unconformity above the Lafayette. Of much more significance, in the judgment of the writer, is the constitution and physical condition of the Lafayette. Dr. Smith says: "As yet the existence of material of glacial origin among the Lafayette beds, seems not to have been proven beyond question" (p. 81). This does not seem to quite express the true condition of things. The Lafayette beds have been widely studied by many observers. Not only has glacial material not been proven to

exist in them, but in the most northern areas of the Lafayette, as shown by numerous exposures, glacial material has been shown to be absent. This is no more than negative evidence against the Pleistocene age of the Lafayette; but the volume of negative evidence is so great that it has carried conviction to every geologist, so far as we know, who has studied critically both the glacial drift and the Lafayette formation.

Concerning the origin of the Lafayette, Dr. Smith appears to incline to the view which has been advocated by McGee, viz., that the Lafayette materials were deposited during submergence of the region which they cover. In this connection a new suggestion is made concerning the relation of the third terraces noted above, to the body of the Lafayette. The suggestion is that in the emergence of the land on which the Lafayette had been deposited, the rivers flowing down over it brought in new material from the north, in this way, perhaps, adding a land accumulation to the marine accumulation which had already been made. It is suggested further, that in the course of time these streams came to be confined in more or less well-defined valleys of their own development, and that at some stage during the uplift, there was a halt of such duration that the broad valleys which these streams occupied were filled up by the streams to the level of the third terraces. This would make the third terraces "the last episode of the Lafayette drama." As the valleys were filled, the coarse materials lodged first, and the fine later, thus giving the relations which are found to exist. Dr. Smith points out very distinctly that these third terraces of Lafayette-like material do not grade into the second terraces, as has sometimes been supposed.

A good deal that is new appears in connection with the Miocene. Two distinct divisions of the Miocene are recognized. The uppermost is the Pascagoula, which has a thickness of something like two hundred feet. It is composed mainly of clays, with more or less green sand. Below this lies the Grand Gulf formation, the age of which has been definitely fixed as lower Miocene.

The data of this report concerning the Eocene have been largely published before in Bulletin 43 of the United States Geological Survey. The present report proposes some modifications in the classification there given, and publishes some new facts, the result of recent field work.

The average seaward dip of the Tertiary formations is said to be twenty-five to thirty feet per mile. Even these young and, on the

whole, regularly disposed formations are not free from considerable deformations. A fault has been found in the western part of the state, having a vertical throw of at least 200 feet. Two distinct and broad, though rather low, anticlines have been found in the same region. Both of them have a northwest southeast course. Neither of them appears to have affected the drainage of the region where they occur.

The subdivisions of the Cretaceous are given above. It is worthy of note that the four subdivisions of the formation which occur in the western part of the state cannot all be carried across to the eastern border, the two uppermost members, the Ripley and the Rotten Limestone, losing their distinctness. The name *Selma Chalk* is proposed as a substitute for the old name "Rotten Limestone," and it is to be hoped that the change may be generally adopted.

In connection with the Cretaceous, it is pointed out that the Tuscaloosa is probably the equivalent of the Amboy (Raritan) clays of New Jersey, and that this formation seems to hold its character from Massachusetts to Alabama. Judged from the physical standpoint, the other members of the Cretaceous of Alabama cannot be said to have much in common with their northern equivalents.

Many details are given concerning the palæontology of the formations described. The microscopic fossils, as well as the larger ones, have received a considerable measure of attention.

Through the whole series of the Cretaceous, Tertiary and Pleistocene formations of Alabama, the influence of the Mississippi River has been felt, a large part of the coastal plain region of Alabama coming within the great Mississippi embayment of these periods. The rivers which cross the coastal plain are all of recent origin.

The later part of the volume is occupied by county descriptions which possess a local interest, and give many sections which will be of value to students of coastal plain geology, since they will offer a basis for classification and correlation.

The economic resources of the coastal plain region are not neglected. This part of the state is far less rich in economic products than the northern part, where the great iron and coal industries flourish. Nevertheless the phosphates and clays of the central and southern parts of the state are of value, and when more extensively used the former seem destined to have an important bearing on the agricultural welfare of the state.

The phosphates are found at several horizons, but the most impor-

tant are at or near the base, and at the top of the Selma Chalk. The phosphate-bearing member at the base of the series is known as the "Eutaw, Hamburg, Selma Belt" because it is well developed at those places. For a similar reason the phosphate-bearing member at the top of the series is known as the "Livingston, Fort Deposit, Union Springs Belt." In limited quantities phosphates have also been found in other parts of the same formation. Each of the principal phosphate horizons consists, not of one stratum, but of several different strata containing phosphates in various forms. They are extensively developed throughout the Cretaceous area, from the northwest part of the state to the Georgia border.

The phosphates at the base of the Selma Chalk occur as nodules and phosphatic casts of fossils, as phosphatic sands and glauconites, or as calcareous marls containing more or less phosphate. The nodules are associated with numerous worn and rounded casts of Cretaceous fossils, such as ammonites, baculites, nautili, etc., which are also often highly phosphatic, as well as with many sharks' teeth and bones of saurians. These nodules and fossils are enclosed in a soft, calcareous matrix, and sometimes in glauconite. The nodules and some of the fossil casts are the richest phosphates found, and often contain from 40 per cent. to over 80 per cent. phosphate of lime. The phosphatic sands, glauconites and marls are much lower grade, containing from 1 to 20 per cent. of phosphate of lime, and often averaging not over 1 to 3 per cent., but they are in much larger quantities than the nodules. The phosphates of the "Livingston, Fort Deposit, Union Springs Belt," are similar to those of the lower horizon.

The Tertiary strata, as well as the Cretaceous, sometimes contain phosphates, but they are less abundant, and are of lower grade. They occur mostly in the Lignitic, White Limestone and Claiborne members of this series, and are in the form of scattered nodules and phosphatic marls.

It is shown that the phosphate deposits occur along lines of non-conformity, and that the fossil casts, etc., are all more or less worn. Professor Smith supposes the presence of the phosphates to be due to the phosphatization of fossil casts, marls, limestones, etc., during the formation of these non-conformities, and the source of the phosphates he ascribes to the decay of animals and plants, and of phosphate-bearing rocks. He shows that though the phosphate localities rarely possess sufficient quantities of high-grade material to be profitably shipped, yet the

phosphates and phosphatic marls are of great use to the farmer in the vicinity. The purely calcareous marls are discussed, and their value shown. The clays for pottery, brick and tile making are also briefly treated, and some of them are shown to be of good quality.

Dr. Smith's work has been carried on unostentatiously for many years. The present volume is not the first piece of good work which he has done. The large results which he has brought out are altogether incommensurate with the meager appropriations which have been at his disposal. While the co-operation of the United States Survey has been of much service to his work, a service which he fully acknowledges, much credit still belongs to the state geologist himself.

ROLLIN D. SALISBURY.

Dr. K. v. Chrustschoff, Ueber Holokrystalline Makrovariolitische Gesteine. Memoires de L'Academie Imperiale des Sciences de St. Petersbourg, VII. Série, Tome XLII., No. 3. St. Petersbourg, 1894. 4to, 244 pp., 3 plates and 37 figures.

The author in his introduction refers to the work already done on the subject, and shows how in the case of the true variolite ("an endomorphic contact phenomenon of diabase") the consideration of the origin is simple in comparison with the genetic history of the orbicular structure in holocrystalline, eugranitic, plutonic rocks. The origin of these are entirely different.

Finding the references to these holocrystalline orbicular rocks to be unavailable he collected them and presents a bibliography of the special studies on spheroidal building, orbicular granites, diorites, gabbros, and diabases.

As the most direct means of approaching the subject Chrustschoff chooses six of the more noted occurrences of variolitic rocks, along with four new occurrences (two in Sweden, one in Silesia, and one in Siberia), making ten, which serve as the subject of discussion for the volume. With each example the author carefully analyses the varioles into an inner core (kern) and various concentric rims (calotte) which may or may not possess radial arrangements in conjunction with their neighbors. The mass of the rock and each of these divisions is in turn studied carefully, and the optical characteristics, order of sequence in crystallization, and very frequently the chemical composition of the various constituents are discussed in detail.

Considered separately the author reaches the following conclusions:

1. Variolitic granite from Altai, Siberia (new locality).

The chemical and mineralogical compositions of the granite magma, the core and the shells of the varioles are such that they show that here is an endogenous contact formation, since the core is more basic and does not belong to the granite magma. Judging from the zircons[1] the core "is the last remnant of an inclusion of the nature of biotite-gneiss resorbed by the granite." Further, "as when a crystal of a salt is suspended in a saturated solution of salts the salt, like the crystal, is the first precipitated and then the others, so if orthoclase were caught up in the magma the orthoclase of the magma would crystallize first, then the isomorphous plagioclase." By this time the feldspar exerts only a directing influence, so that the biotite crystallizes and is oriented with regard to the feldspar interior.

2. Variolitic amphibole-granite from Rattlesnake Bar, California.[2]

The dark green rock which contains the spheroids consists of a granular mass of cloudy gray feldspar, pellucid quartz, and abundant brownish green hornblende. The varioles are more or less regular ellipsoids with diameters of 8 cm., 5 cm., 6.5 cm. respectively, and represent basic inclusions of a foreign rock, or a more basic primary secretion from the amphibole-granite magma, which have been resorbed in part by the magma. As the cooling, pressure, water contents, etc., changed, a new crystallization took place about the included remnant forming a concentric layer of minerals produced from the preëxisting magma saturated with the included substance. This action continued until the circumstances existing in ordinary granitic formations had gained the upper hand.

The spheroidal form tends towards a more rapid crystallization, and so the secretion of concentric layers follows more rapidly than the individualization of the surrounding granitic magma. From the already formed core go out certain directing influences so that the amphibole, the ores, and part of the feldspar force themselves into a radial arrangement.

3. Variolitic granite from Kunnersdorf, Silesia (new locality).

The granite mass, in which the 8–15 cm., rounded to angular spheroids lie, consists of reddish gray, medium fine-grained feldspar,

[1] Vid. CHRUSTSCHOFF, Zur Kenntniss der Zirkone in Gesteine. Tschermak's Min. und Petr. Mitth. Bd. XII., p. 423.

[2] VOM RATH: Sitzungber. d. niederrh. Ges., December, 1884.

quartz, silver-gray muscovite, and biotite. The spheroids were formed in the following way:

During the eruption of the granitic magma fragments of a foreign granitic rock were surrounded by the granitic magma. The solid granite may have been "foreign" or it may have been from the already solidified portions of the magma. Resorption began and continued until the magma was supersaturated and the temperature lowered to a point where a new crystallization could begin.

The included granite consisted of orthoclase phenocrysts in a fine-grained groundmass which was more readily dissolvable than the compact feldspar. Though the phenocrysts did not remain entirely unattacked they were not completely resorbed, and an outer mixed zone was formed between them and the individualized magma. The subsequent crystallization took place in the mixed zone under the orienting influence of the feldspar. At the moment when crystallization reached the outer zone of influence the whole magma crystallized to a panidiomorphic-granular mixture.

In this case, as in the first, the character of the zircons proved a valuable aid in the interpretation of the varioles' genesis. The main mass and the core carried zircons of different habits, while the shell of the variole carried both types.

4. Variolititic granite from Ghistorrai near Fonni, Sardinia.

As in the cases above cited fragments of different rocks were surrounded and taken into the granitic magma, where their constituents were disassociated and in part resorbed. From this simple proposition it would seem that the rocks under consideration would be other than rare; there are, however, certain conditions essential to "kugelbildung."

"The inclusions must be concentrated within the predominant rock magma to the smallest possible space so that between them a relatively small amount of magma remains included. The enclosing part of the magma then enters into an exchange with the inclusion, and there is established corrosion, resorption, and recrystallization, though the magma may circulate very slowly between them, *e. g.*, bringing in from without and distributing from within. In consequence of this action the mixed zone supersaturated with material from the inclusion may remain stationary a long time. Under such circumstances a rapid crystallization tending towards a radial structure may set in more readily than in homogeneous granite where the crystallizing conditions naturally must be distributed equally." P. 129.

5. Variolitic specimen from Amtensee, Grythyttau, Orebrö, Sweden (new locality).

A careful petrographic description is given, but the material was insufficient for a study of its genesis.

6. "Pudding granite" from Craftsbury, Vermont.

"This is a biotite-muscovite-granite which contains concretions of biotite that are quite uniform in size and usually about an inch and a half in diameter. They are spherical or spheroidal in form and corrugated on the surface."[1]

Here Chrustschoff considers that the development of the variole falls into the period of the development of the mica in the host and the spheroids appear to be developed through the local increase of a character inherent in the entire mass; in the variole the quartz-feldspar complex is surrounded by a zone of mica broader and thicker than in the homogeneous rock. The whole phenomenon is considered as the result of concretionary action.

7. Feldspathic variole from Aldersbäck, Sweden (new locality).

The sum of the observations indicates that this variole is a resorption residue of a holocrystalline, macrovariolitic rock.

8. Variolitic quartz-diorite from Svartdal, Norway.

Here the ores and apatite balled into a glomero-porphyritic mass served as a center of crystallization so that the rock is "consequently determined as an original macrovariolitic quartz-mica-dioritic, whose spherulitic form of structure is autogenetic and due to the constitution, as well as to the mode of solidification, of the magma." P. 177.

9. Variolitic gabbro from Romsas, Askim, Norway.

The varioles were local developments along the sides of a laccolitic mass and were mechanically disseminated, locally, through the mass. The varioles crystallized under intratelluric conditions and subsequently had formed about them a rim of amphibole.

10. Variolitic amphibole-granite from Slattmossa, Sweden.[2]

Here the core is more basic than the mother rock, and we thus conclude that it is an old basic secretion around which have been formed shells of intermediate acidity. This rock, consequently, is not an original macrovariolite, but is the product of an early secretion of basic material.

The above résumé of the results and conclusions reached shows that macrovariolitic rocks belong genetically to at least four classes:

[1] HAWES, Lithology and Mineralogy of New Hampshire, Vol. II., Part IV., p. 203.
[2] HOLST, Geol. Foren., Stockholm, Forhandlung, Bd. VII., p. 135.

1) Those of concentric spheroidal form produced by foreign inclusions.
2) Those where the varioles were formed by the partial resorption of fragments of the locally solidified magma.
3) The so-called "pudding granites," due to a concretionary action.
4) Those varioles which are primary structural forms of the magma, or are due to endomorphic contact action.

The *conditions* requisite for the formation of varioles are:

1) A difference in the basicity within the magma.
2) The cores must be near each other.
3) There must be a difference in temperature between the core and the magma.
4) The temperature must be high enough to aid resorption but not sufficient to permit the complete resorption of the fragments.

While the work is occupied primarily with a study of the origin of macrovariolitic rocks, it is full of incidental studies of the minerals encountered. This is especially true of zircon, the feldspars, and perthitic intergrowths, while there are many suggestive points on phenomena frequently seen in quartz, apatite, hornblende, etc. On the whole the work is an example of a careful, exhaustive study of a circumscribed problem.

EDWARD B. MATHEWS.

On the Banded Structure of Some Tertiary Gabbros in the Isle of Skye. By SIR ARCHIBALD GEIKIE and J. J. H. TEALL. Quart. Jour. Geol. Soc., November, 1894. Vol. I., pp. 645–659. Pls. XXVI., XXVII., XXVIII.

THE importance of this study of the Tertiary gabbros of Skye is twofold, as pointed out by the author: First, as a contribution to our knowledge of the structures which may be assumed by igneous rocks at the time of their solidification, or prior to their consolidation. Second, as an aid to the elucidation of some of the most perplexing problems in the study of the crystalline schists.

The rocks described are part of the volcanic complex which forms the picturesque group of mountains known as the Cuillin Hills in the southern portion of the Isle of Skye — a vast aggregation of indurated tuffs, agglomerates, lava-flows, besides intruded bodies that have broken

through the earlier accumulations, and have been exposed to view by subsequent erosion.

The gabbros in question are among the more recent rocks, though not the latest, and exhibit no trace of crushing, recrystallization or other signs of metamorphism. They appear to have remained in the condition in which they originally crystallized. Moreover, no great terrestrial disturbance has affected the region since the time of their eruption. They are said to form sheets or sills varying from a few feet to many yards in thickness, each band consisting of many parallel layers of lighter and darker material, which correspond to the trend of the sheet itself. The component layers vary in thickness from mere pasteboard-like laminæ to beds a yard or more in thickness. They are sometimes as parallel and regular as sedimentary deposits. But, traced along the strike, they are apt to vary in thickness and even to die out. Their appearance is quite like the banding of gneisses.

The microscopical study of these rocks shows their mineral constituents to be like those of normal olivine-gabbros, and the differences between the light and dark bands to be due to differences in the relative proportions of the minerals.

The crystallization of the mass is continuous across the bands, the individual crystals interlocking in such a manner as to make it evident that all crystallized from a molten magma at approximately one time. The white bands in some cases consist almost entirely of labradorite, while the extreme dark bands are made up of augite and titaniferous magnetite.

The cause of these differences in composition of alternate layers of gabbro is considered to be a differentiation of the magma previous to its intrusion among the rocks in which it consolidated. The banding is the result of the intrusion of a heterogeneous magma. The original shapes of the more or less differentiated masses that composed this heterogeneous magma are not known, their intrusion through fissures would produce a laminated arrangement.

A comparison of these rocks with certain ancient gneisses is drawn, especially with the anorthosite rocks of Canada, and with certain ultrabasic portions of the Lewisian gneiss of Scotland; the similarity in their structures is pointed out, and a correspondence in their origin is suggested.

The analogy between the banding in both these kinds of rocks strengthens the view now generally held by geologists, that the older

gneisses are mainly rocks of igneous origin. While recognizing the undoubted evidence of secondary dynamic action in many regions, and the absence at present of criteria by which original and secondary structures may be discriminated, the authors are strongly of the opinion that much of the banding of gneisses, as distinguished from mere foliation, may be an original structure due to the conditions in which the igneous magma was erupted and consolidated.

The necessity of establishing the prevalence of such differentiated lamination in basic rocks, and of recognizing its occurrence to any considerable extent in granitic masses, is self-evident after the bearing of such facts on the nature and origin of the ancient gneisses has been so clearly set forth.

JOSEPH P. IDDINGS.

Preliminary Report on the Geology of South Dakota. By J. E. TODD, State Geologist. (South Dakota Geol. Surv., Bul. No. 1, 172 pp., 5 plates, Prelim. Geol. Map. Sioux Falls, 1895).

Summaries of the progress up to date along a particular line of work, or of the knowledge of the geology of particular regions are always welcome. This is particularly true when the report covers a region of so wide and varied interest as South Dakota and one the literature of which is so badly scattered. Since the early work of Hayden in the eastern and of Newton and Jenny in the western half of the state the papers on the geology of South Dakota which have appeared have been fragmentary only. They have, however, modified our ideas of the geology of the region in many important regards. As a foundation for the future work of the Geological Survey Todd has brought together in convenient form all this mass of information and has added to it, as a result of his several years work in the region, a great deal that is now for the first time published.

Among the new points which may be noticed are, the recognition of the Silurian as present in the Deadwood section and the pointing out of the beds which must represent the Devonian if it be at all present. A number of caves in the Carboniferous are described in detail. In one of them, Wind cave, is a curious calcite formation called "box-work." The peculiar dome-like surface of the Purple Limestone, it is suggested, may be due to the leaching out of salt beds of irregular thickness below. The marine origin of the Dakota is

argued for, the material of which it is composed being supposed to have been derived from the Sioux quartzite or possibly the Carboniferous of the Mississippi Valley. The author follows King in grouping the Benton, Niobrara and Pierre as Colorado and does not recognize the Montana, the Fox Hills being mapped alone as the Fox Hills Group. In the present state of knowledge this is undoubtedly almost a necessity so far as mapping the area is concerned, but it is to be hoped that more detailed studies will allow the divisions now so generally recognized elsewhere to be differentiated. The White River beds are described in detail, especially interesting notes on the presence in them of sand-dikes being given. At the Bijou Hills a fine-grained quartzite of greenish tinge is noted in the Loup Fork beds. Certain obscure beds of sand and clay in the eastern part of the state and in part in Iowa are somewhat doubtfully referred to latest Pliocene or earliest Pleistocene time and are considered as possible lacustrine beds contemporaneous in age with Lake Cheyenne.

Four moraines are traced: the First or Altamont, Second or Gary, Third, and Fourth. On the map these are not marked, the limit of drift alone being shown. The drift found in the Black Hills region is considered to be "a kind of delta deposit formed by streams shifting to and fro upon a plain of deposition." Some very interesting facts regarding river terraces which may clear up some of the doubt regarding the early history of the rivers in the region are given.

In a résumé of the geological history of the region it is pointed out that the eastern half of the State was dry land during Palæozoic time, and from this it is argued that the condition for the formation of coal existed during the Carboniferous and that mineral may, perhaps, be found to occur in the middle of the State. In the chapter on economic geology the various minerals, building stones, artesian wells, and other similar topics are briefly discussed.

The report contains the usual number, or perhaps more than the usual number, of typographical errors; fortunately, however, very few confuse the meaning. It is an exceedingly compact and valuable compendium of the geology of this comparatively unknown but very rich geological province.

H. F. Bain.

The Geomorphogeny of the Coast of Northern California. By ANDREW C. LAWSON. (Bulletin Geological Department of the University of California, Vol. I., No. 8, November, 1894).

This paper gives the results of Professor Lawson's study of the coast north of San Francisco. It is a continuation of the study south of that point as published in No. 4 of the above publication. The topography of the northern coast of California is that of a dissected table-land sloping from an altitude of 1600 feet on the coast to 2100 feet farther east. In the vicinity of Eel River this plain truncates the edges of a sharp syncline of Pliocene beds, having a thickness of more than a mile.

The axis of the syncline is normal to the coast. Of the 36 species represented by fossils only 14 are extinct, while 18 are not known in the Miocene. Along the coast are numerous well-developed ocean terraces at various levels up to the top of the table-land. The streams are more precipitous in their lower than in their middle courses. The Eel River, owing to the softness of the Pliocene beds—the Wild-Cat series—has a broad flood-plain in contrast to the gorges of the other streams formed in the hard Mesozoic sandstone. In the vicinity of San Francisco the channels cutting across the lower terraces are sunken, giving a fjord-like character to the region and forming the Golden Gate and Bay of San Francisco.

The history of the region described is read by the author as follows: (1) The formation of a great coastal peneplain in Pliocene times accompanied by the accumulation of marine sediments. To this period belongs the deposition of the Wild-Cat series which took place *pari passu* with the sinking of that area. (2) The orogenic deformation of parts of this plain and folding of Pliocene beds without changing the general altitude of the peneplain. (3) The reduction of upturned Pliocene beds to baselevel and the limited extension of the peneplain between uplifted blocks of other areas. (4) The progressive uplift of this peneplain to an altitude of 1600 to 2100 feet, the adjacent mountains being influenced by the same elevation. The stages of this uplift were marked by the coastal terraces, but the halts were, in general, too short to produce stream terraces by side shifting. (5) The erosion of the uplifted peneplain to the present stage of late adolescence or early maturity. In this erosion, structure and relative hard-

ness have been all-controlling. (6) A very recent sag of 100 miles of the coast at the Golden Gate, forming a syncline, the axis of which is probably parallel to the coast. This subsidence is about 378 feet at its maximum point. A. R. W.

Geological Survey of Alabama. EUGENE ALLEN SMITH, State Geologist. Geological Map of Alabama with Explanatory Chart. 1894.

The map is on a scale of ten miles to an inch, the base being compiled from the records of the United States Land Office, and free use having been made of the atlas sheets of the United States Geological Survey. As shown by the map many of the formations from the pre-Cambrian crystallines to the Pleistocene alluvial deposits are found in the state. There are the Chilhowee sandstones and the Knox shales and sandstones of the Cambrian, three members of the Silurian, one of the Devonian, the sub-Carboniferous and the Coal Measures, four subdivisions of the Cretaceous, four of the Eocene, the Lower and Upper Miocene, the Pliocene (Lafayette) and the Pleistocene.

The map is accompanied by an explanatory chart which is very valuable in presenting in a concise and tabulated form the important facts concerning each of these formations. In the first column are given the names, synonyms, classification and common fossils of each of the formations represented on the map. Another column gives the thickness, the lithological and topographical characters, the area and the distribution. In a third column are placed the useful products found in each formation. The respective soils, characteristic timber growth and agricultural features are briefly given, and also references to the reports in which the formations are more fully described. Some such scheme as this, modified as the exigencies of the case might require, would add greatly to the value of all general geological maps. H. B. K.

Some Coal Measure Sections near Peytona, West Virginia (with two large maps). By BENJAMIN SMITH LYMAN. (Proceedings American Philosophical Society, Vol. XXXIII., November 2, 1894, pp. 282–309.)

This paper contains the results of two preliminary surveys made in 1872, near Peytona, Boone county, West Virginia. The tracts covered by these surveys lie, the one twenty-two miles south of Charlestown, the

state capital, and the other near Brownstown on the Kanawha about ten miles above Charlestown. The peculiar topography, *i. e.*, flat, table-like hilltops here and there, flat valleys, and many cliffs on the almost uniformly abrupt hillsides, is due to the level bedding of a great thickness of rocks at a sufficient height above sea-level. In the Peytona tract the beds dip 51¾ feet to the mile, southeasterly, with slight local variations which cause "swamps" in the mines. On the Parker tracts the dip is slight.

The general section of the rocks exposed in both tracts is given in detail. Of a total thickness of 800 feet in the Peytona tract there are thirteen coal seams with a total thickness of twenty-two and a quarter feet. There are also several very thin seams of iron ore. In the Parker tract the total thickness is 640 feet, and eight coal beds with a total thickness of twenty-one feet. For purposes of comparison Professor Stevenson's general table of the section of Carboniferous rocks for the northern edge of West Virginia is given, and many of the coal seams of these tracts are correlated with important seams in Pennsylvania and northern West Virginia. H. B. K.

RECENT PUBLICATIONS.

—FAIRCHILD, HERMAN LE ROY, The Length of Geologic Time, 4 pp.
The Geological History of Rochester, N. Y., 9 pp.
The Evolution of the Ungulate Mammals, 4 pp. (Abstract.)
—Proc. Rochester Academy of Science, Vol. II.

—GRESLEY, W. S., F.G.S., The "Slate Binders" of the "Pittsburg" Coal Bed, 10 pp.—Am. Geologist, Vol. XIV., December, 1894.

—MEAD, DANIEL W., The Hydro-Geology of the Upper Mississippi Valley and of Some of the Adjoining Territory, 58 pp. and 11 maps.—Jour. of the Assoc. of Eng. Socs., Vol. XIII., No. 7, July, 1894.

—READE, T. MELLARD, C.E., F.G.S., F.R.I.B.A., The Dublin and Wicklow Shelly-Drift, 23 pp., 4 plates.—Proc. Liverpool Geol. Soc., 1893–94.

—ROLFE, C. W., M.S., List of Altitudes in the State of Illinois, 100 pp.
Bulletin of the Illinois State Laboratory of Natural History, Vol. IV., Article IV.

—STEENSTRUP, K. J. V., Meddelelser Fra Dansk Geologisk Forening, 14 pp.

—SPENCER, J. W., M.A., Ph.D., B.A.Sc., F.G.S., The Yumusi Valley of Cuba—A Rock Basin, 4 pp.—Geol. Mag., Decade IV., Vol. I., No. 365; November, 1894.

—TAYLOR, F. B., The Limit of Post-Glacial Submergence in the Highlands east of Georgian Bay, 17 pp., 1 plate.—Am. Geologist, Vol. XIV., November, 1894.
Reconnaissance of the Abandoned Shore Line of Green Bay and of the South Coast of Lake Superior, 67 pp.—Am. Geologist, Vol. XIII., May–June, 1894.

The Highest Old Shore Line on Mackinac Island, 9 pp.—Am. Jour. Sci., Vol. XLIII., March, 1892.

The Ancient Strait at Nipissing, 1 plate, 7 pp.—Bull. Geol. Soc. Am., Vol. V., 1893.

—WESTGATE, LEWIS G., The Age of the Crystalline Limestones of Warren County, New Jersey, 11 pp.—Am. Geologist, Vol. XIV., December, 1894.

NOTES.

THE Wisconsin Academy of Science, Arts and Letters is making a systematic and vigorous effort to establish a geological and natural history survey of the state. A strong statement of the need of such survey to extend the work of the last one, which was closed about fifteen years ago, has been printed and widely distributed, and the importance of the subject personally brought to the attention of educators, leading citizens and members of the legislature. A bill has been drawn carrying an annual appropriation of $15,000 to be expended under the direction of a wisely constituted commission. The plan for the proposed survey is broad and comprehensive, and yet confined to legitimate and practical lines of investigation. It is to be hoped that the effort will be successful.

AT the recent meeting at the Academy, Professor C. R. Van Hise read a paper on "The Relation of Bedding to Secondary Structures of Rocks," and Professor G. E. Culver discussed "The Abrasive Action of Ice."

A MOVEMENT is being made to secure the establishment of a geological survey of the state of Washington, and an appropriation will be sought from the legislature for that purpose. It is proposed, we understand, to connect the survey with a mining department of the state university, to be simultaneously established.

A VERY commendable effort is being made by Director Walcott of the U. S. Geological Survey, supported by Prof. Harris, U. S. Commissioner of Education, to secure provision for the printing and distribution, to the higher schools of the country, of a set of ten topographic atlas sheets, selected so as to represent types of surface configuration. The distribution is to embrace Grammar, High and Normal Schools, Academies, Colleges and Universities. The maps, it is claimed, can be printed at a cost not exceeding 2.06 cents per sheet. It is estimated that there are about 15,000 schools of the grade that would be entitled to the maps, and that the total cost including distribution would be $5,000, or one-third of a dollar per school. There has already been a considerable demand on the part of teachers for the topographic sheets, and during the past year 300 sets have been distributed in response to such requests, but present provisions are inadequate to a general distribution. With the rejuvenation of the study of geography which is taking place under the influence of modern methods in surface geology, the use of such maps will be very great, indeed they will become indispensable. There should be no hesitancy on the part of Congress in making the desired provision.

DR. A. R. C. SELWYN, after a long term of service as director of the Geological Survey of Canada, marked by large and important results, has retired from its administration and will, we understand, spend some years abroad. Dr. G. M. Dawson succeeds to the directorship.